Assessment of inner volume imaging technique for renal tissue characterization by IVIM and DTI at 3 T

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Purpose: Diffusion tensor imaging (DTI) and intravoxel incoherent motion (IVIM) imaging have been shown to be useful in the analysis of renal architecture and function both under healthy and pathologic conditions [1-7]. Single-shot diffusion-weighted spin-echo echo-planar (DW-SE-EPI) imaging sequences are commonly used in abdominal DWI due to their low sensitivity to artifacts from physiologic motions. However, EPI techniques can suffer from geometric distortion and artifacts due to susceptibility gradients and static field inhomogeneity. The magnitude of these distortions and artifacts depends on the echo spacing and echotrain length (ETL). Inner volume imaging (IVI) is a promising approach to reduce ETL [8]. The aim of the study was to compare the application of IVI and standard full-FoV (FF) for DWI of the kidneys in healthy volunteers at 3T.

Methods: *Experimental:* Six healthy volunteers underwent MRI of the kidneys at a clinical 3T scanner (Skyra, Siemens Healthcare, Erlangen, Germany). DTI and IVIM were performed in coronal slices both with standard FF and IVI technique (sequence parameters, Table 1). IVI was implemented by application of 2D selective excitation radiofrequency (rf) pulses replacing the standard slice selective excitation. The two dimensions of the excitation volume were used to restrict the volume in slice selection and phase encoding direction [9]. All DW images were acquired respiratory-triggered using a compressible belt.

	Full-FoV (FF)	Inner Volume Imaging (IVI)
TE (ms)	77	85
Matrix	129×192	51×142
FoV (mm^2)	400×400	160×300
Phase resolution (%)	67	
Phase FoV (%)	100	53.5
Partial Fourier	6/8	
Parallel imaging factor	2	1
BW (Hz/Pixel)	1736	1760
Signal averages	4/3	
b-values, DTI (s/mm^2)	0, 400	
b-values, IVIM (s/mm^2)	0, 50, 100, 150, 300, 500, 700	
Diff. directions, DTI	30	
Diff. directions, IVIM	3 (3 scan-trace)	
Number of slices	16	
Slice thickness (mm)	3.5	
TR (ms)	1700-1800	1700-1800

Table 1: Sequence parameters for DTI and IVIM imaging.

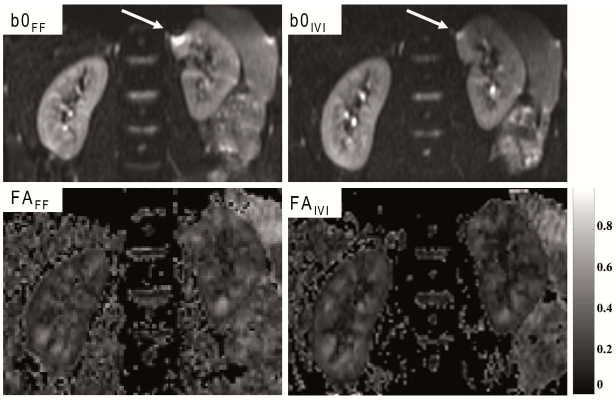

Figure 1: Qualitative comparison of FF and IVI.
Coronal DW image (b0) and FA map of the kidneys acquired with standard full-FoV (FF, left) and inner volume imaging (IVI, right). IVI technique showed less distortion and artifacts (white arrow) with subjectively better parametric maps. FF images are zoomed in from the whole FoV for comparison.

Image and statistical analysis: Qualitative and quantitative image analysis was performed for comparison of FF and IVI. For calculation of the parametric maps, images were co-registered using Statistical Parametric Mapping (SPM8, Wellcome Trust Centre for Neuroimaging, London, UK) software and processed using Matlab (The MathWorks, Natick, USA). The qualitative analysis of DW images and parametric maps (FA=fractional anisotropy, D=mean diffusivity, ADC=apparent diffusion coefficient, f_P=perfusion fraction) was performed by two experienced radiologists in consensus on a five-point scale (1 = excellent; 5 = non-diagnostic). The following criteria were evaluated: renal contour sharpness, presence of distortion and artifacts, noise, visual impression of image quality. For quantitative evaluation the parameters FA, D, ADC and f_P of renal cortex and medulla were measured in ROI analyses in representative slices. The ratio $FA_{medulla}/FA_{cortex}$ was calculated for each kidney. Qualitative and quantitative results of FF and IVI were compared using Wilcoxon rank-sum. P values < 0.05 were considered statistically significant.

Results: DTI and IVIM were feasible both with FF and IVI technique. In the qualitative comparison distinctly reduced distortion and less prominent areas with signal voids were observed in IVI images while they were rated noisier. The majority of parametric maps obtained by IVI was subjectively rated better (Figure 1), although no statistical significance was reached. In the quantitative analysis, higher FA values were found for medulla than for cortex in both techniques with no significant difference of the ratio $FA_{medulla}/FA_{cortex}$ between FF and IVI technique (2.2±0.5 vs. 1.9±0.4; p=0.060). Significant differences between FF and IVI technique existed for D in the cortex and for ADC and f_P both for cortex and medulla (Table 2).

Table 2:
Quantitative comparison of FF and IVI.
ADC and D given in 10^{-3} mm^2/s, f_P in %
D calculated from DTI data
ADC calculated from IVIM data

	D_{cortex}	$D_{medulla}$	FA_{cortex}	$FA_{medulla}$	ADC_{cortex}	$ADC_{medulla}$	$f_{Pcortex}$	$f_{Pmedulla}$
FF	2.6±0.9	2.7±.2	2.3±0.4	4.9±0.6	1.8±0.3	1.5±0.5	17.5±6.7	19.7±9.4
IVI	2.4±0.2	2.4±0.3	2.2±0.4	4.2±0.7	1.4±0.3	1.3±0.3	28.6±7.6	34.2±6.2
P	0.01	n.s.	n.s.	n.s.	0.002	0.03	0.002	0.003

Discussion: IVI is a promising approach for improving image quality of DTI and IVIM of the kidneys. Images acquired with IVI technique revealed reduced distortions and signal void artifacts compared to standard FF technique. However, IVI technique provided images with slightly more noise which may be partially explained by the longer TE and reduced matrix size. New parallel transmission technologies might be used to reduce the duration of the 2D rf excitation pulse in IVI technique and thus reduce TE in the future[10]. The observed parametric values for renal tissue characterization were in accordance with the literature [6,7]. In IVI technique, slightly lower ADC and D values and higher f_P were observed in comparison to the FF technique both for cortex and medulla. Possible explanation for this discrepancy might be a non-negligible but unaccounted distribution of the slice excitation gradients for the calculation of the b value, which differ for the IVI and the FF sequence. Limitations of the study include the relatively small volunteer number and the healthy study population. To conclude, IVI technique is a promising approach for improving DWI of the kidneys. The application in patients with renal diseases is necessary to assess its clinical performance.

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