Real-time *SP*atiotemporal *EN*coding Imaging (SPEN MRI) of Renal Kinetics in Perfused Mice

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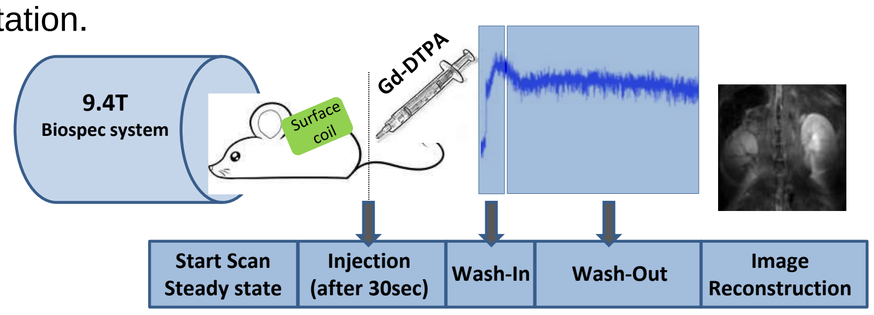
1. Introduction

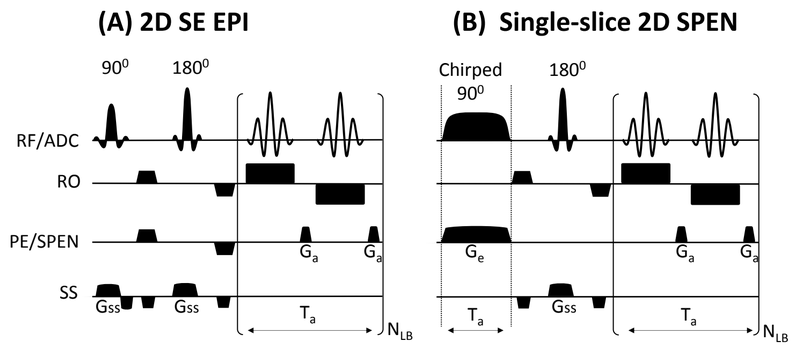
Real-time MRI aims to monitor fast dynamic processes by using fast or "ultrafast" (single-scan) schemes. ***SP***atiotemporal ***EN***coding (SPEN) is an ultrafast method[1] (<50ms per scan) capable of delivering single-scan 2D images even in inhomogeneous environments[2]. SPEN can also deliver images that are fully refocused vis-à-vis T2*; and therefore is a natural candidate for achieving this objective at high fields. The aim of this study was to explore SPEN's ability to deliver real-time dynamics of contrast material (CM) injected to mouse kidneys. In the study herein presented, SPEN-based strategies are compared with similarly structured and timed experiments based on echo planar imaging (EPI) and multi-scan fast-low-angle shot (FLASH).

2. Methods

Healthy mice were anesthetized and Gd-DTPA was injected into the tail vein with a volume of 100 µL and concentration of 0.01 M. The injection lasted 2sec and all experimental scans thereafter amounted to 20min. These experiments took place at 9.4T in a Biospec system (Bruker, Germany) using a surface coil for detection and a linear coil for excitation.

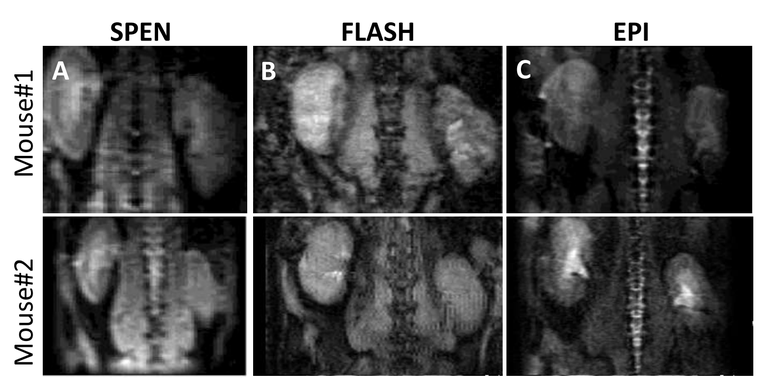


3. Pulse Sequence Consideration



2D single-scan pulse sequences assayed, with their gradients and timing definitions (delays not drawn to scale). (A) 2D Spin-Echo EPI. (B) Single-slice 2D SPEN MRI. All SPEN experiments were run under fully-refocused conditions; i.e., equal excitation and acquisition times. The RF/ADC line displays the RF and signal acquisition; other definitions: G_e = encoding gradient; G_{ss} = slice-selective gradient; G_a = acquisition gradient; T_a = acquisition time; N_{LB} = number of loops encoding the low-bandwidth (PE/SPEN) dimensions.

4. Kidney Anatomy - Pre-Injection Images



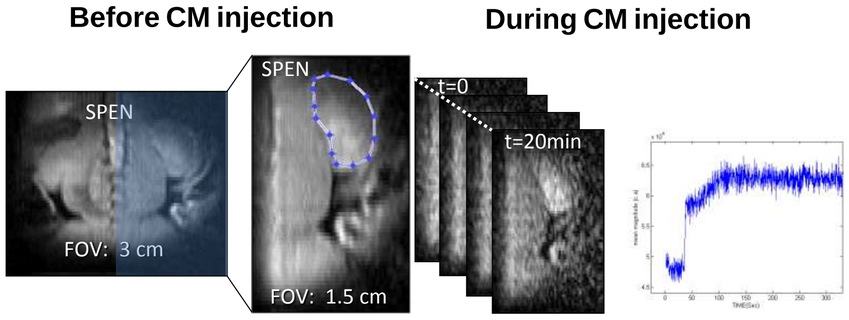
Anatomical images of mouse kidneys before Gd-DTPA injection. (A) 2D SPEN with FOV of 30×30mm and voxel size of 0.3×0.3×2mm. (B) 2D multi-scan FLASH, and (C) 2D SE EPI with FOV of 30×20mm and voxel size of 0.3×0.2×2mm. Scan duration: 50ms (SPEN), 250ms (EPI), 1500ms (FLASH) plus recycling time of 250ms.

The kidneys nature before injecting the CM can be appreciated. The fully refocused SPEN experiment exhibits reduced off resonance effects[2] thanks to its fully-refocused detection throughout the acquisition process. This feature delivered anatomical images free of artifacts, where EPI suffered from inhomogeneity artifacts surrounding the kidneys ROI.

5A. Results (1): Basic SPEN Kinetic Imaging of Kidney(s)

Fast kinetics of 2D SPEN of both Kidneys after Gd-DTPA injection. The plot describes the kinetics of only the kidney circled by ROI. The 2D SPEN with FOV of 30×30mm and voxel size of 0.3×0.3×2mm. Sequence duration of 50ms, recycling time of 250ms, 4000 repetitions for 20min.

The SPEN-based method with the shortest scanning time, showed a clear spatial advantage during the experiment itself since it was the only method that could deliver reasonable images even under ultrafast conditions.

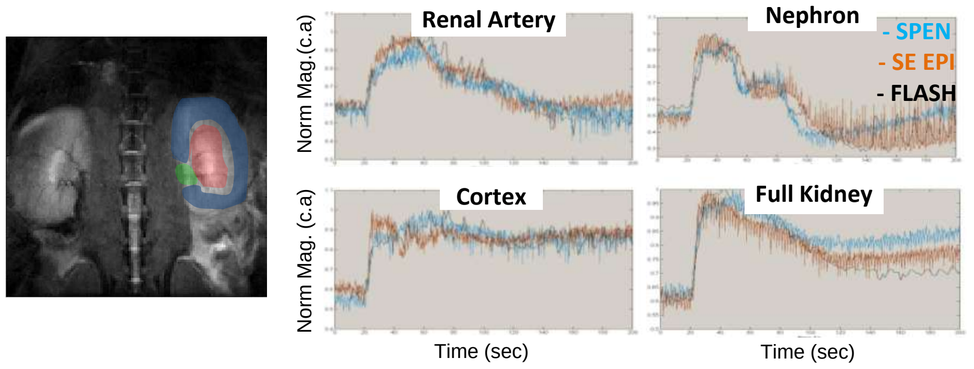


Fast kinetics of 2D SPEN of a single kidney after Gd-DTPA injection. The plot describes the kinetics of the single kidney circled by ROI. The 2D SPEN with FOV of 25×15mm and voxel size of 0.25×0.15×2mm. Sequence duration of 50ms, recycling time of 250ms, 4000 repetitions for 20min.

An important advantage of SPEN results from its ability to deliver "zoomed" images with restricted region of interest (ROI) within the sensitive volume without having to re-position the surface coil and/or suffering from folding-over. Shown on the left is a SPEN perfusion experiment executed as just described, but focusing on an individual kidney.

5B. Results (2): Kinetic Comparisons

The perfusion kinetics measured by SPEN, SE EPI and FLASH imaging is compared for different anatomical ROI's of the kidney. These are described in the FLASH image on the left: Renal-artery (Green), Nephron (Red), cortex (Blue) and full kidney. A good alignment agreement can be appreciated between the three pulse sequences.



6. Conclusions

Artifact-free SPEN images yielded clear images of Gd-DTPA perfusion into kidneys @ 9.4 T. These could be analyzed with high spatial and temporal resolution. This real-time imaging setup can be extended to other challenging biological/ physiological settings where high temporal resolution as well as robustness to field inhomogeneities, are mandatory.

[1] A. Tal, L. Frydman, Single-scan multidimensional magnetic resonance, Prog. Nucl. Magn. Reson. Spectrosc. 57 (2010) 241–292.
[2] N. Ben-Eliezer, Y. Shrot, L. Frydman, High-definition, single-scan 2D MRI in inhomogeneous fields using spatial encoding methods, Magn. Reson. Imaging 28 (2009) 77–86.

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