Fully-Refocused Spatiotemporally-Encoded MRI: Robust MR Imaging in the presence of metallic implants

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Introduction Many orthopedic fractures and joint problems require treatments using metallic implants. The use of MRI as a post-surgery diagnostic tool, however, is hindered in such cases owing to the strong field distortions caused by these implants, manifested by severe signal loss / pile-up, and distortion artifacts. Various techniques, available for overcoming this challenge, include: spin-echoes, constant-time phase-encoding approaches, UTE sequences [1], view-angle-tilting [2], multi- RF offset acquisitions [3], and field-map based post-processing algorithms. The combination of these provides diagnostic capabilities under conditions that until recent years were considered overtly challenging. Notwithstanding, the existence of metallic objects in the target FOV is still an open challenge in MRI. In recent years a conceptually different encoding approach has emerged, based on progressive refocusing in the image spatial (rather than the *k*-space) domain using quadratic phase functions. The ensuing spatiotemporal-encoding (**SPEN**) technique was shown to offer significantly higher robustness against B_0 field inhomogeneities [4-6]. Particularly effective is its ability to implement a unique time-dependent Spin-Echo which fully refocuses all static T_2^* effects for each and every time point –and not just at a single instant as in *k*-domain acquisitions. In view of this promising feature the present work demonstrates SPEN's ability to overcome extreme ΔB_0 distributions arising near metallic implants, where sufficiently long T_2, albeit very short T_2^* values exist.

Methods Experiments were done on a Varian Inova 7T vertical scanner. Cartesian and radial multi-shot SPEN protocols were tested on an *in-vivo* mouse brain attached with a 3mm thick Titanium disc. SPEN sequences used a 180^0 frequency-swept spin-echo pulse and were processed using the super-resolved SPEN reconstruction algorithm presented in [7]. Images were subsequently compared with conventional (*k*-space encoded) Spin-Echo MRI analogues, using identical bandwidth and timing conditions. Both multi-slice and pure 3D scans were performed covering a FOV of 20x20x5 mm^3. Other imaging parameters were: SE-EPI [slice-thickness=1.0 mm, gap=0 mm, matrix size=70x70, TE=6.3 ms, TR=100 ms, overall T_{acq}=0.6 sec]; SPEN MRI [180^0 pulse sweep rate=40 kHz/ms, slice-thickness=0.75 mm, gap=0.25 mm, matrix size=70x70, TE=[4..9] ms, TR=100 ms, overall T_{acq}=0.6 sec].

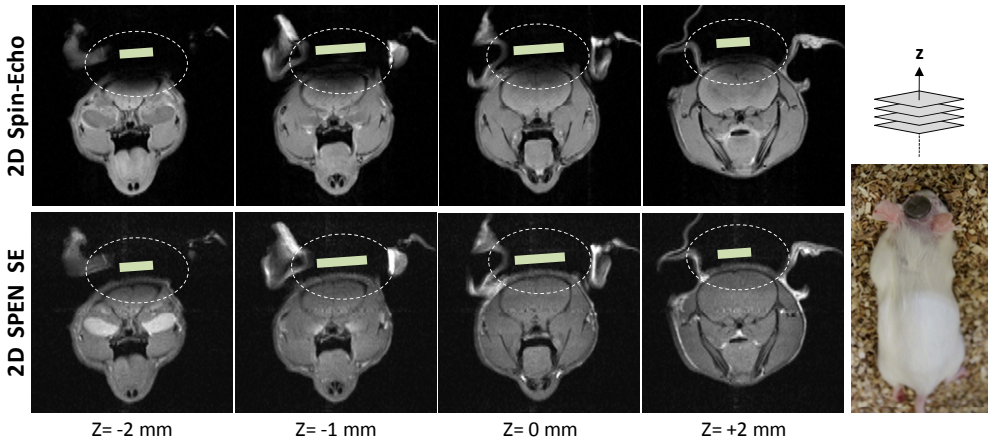

Figure 1: MR images of an in-vivo mouse brain, attached with a 3mm thick Titanium disc. Top: conventional k-space encoding. Bottom: Spatiotemporally-encoded (SPEN) images.

Results Figure 1 shows an example of the quality enhancement afforded by SPEN for *in-vivo* Cartesian imaging of a mouse brain. **Top:** *k*-space encoded 2D Spin-Echo MRI. **Bottom:** Spatiotemporally-Encoded 2D spin-echo MRI. The area, proximal to the Titanium disc is completely dephased in (a), whereas reliable reconstruction is achieved in (b) even in the region right below the metallic object. Also apparent is the different contrast mechanisms associated with SPEN and *k*-space encoding resulting from the different TE associated with each method. Similar results were obtained in the pure 3D and in the radially sampled data sets.

Discussion Originally developed as a general method for single-shot 2D NMR/MRI, the present study clearly highlights SPEN's potential in the context of *multi-shot* imaging. Similar techniques have been previously investigated by Kunz, Pipe, Wong and Shen; This work extends those investigations by exploiting a hitherto untapped resource, associated to the self-refocusing capabilities of SPEN MRI. By equating the bandwidth and duration of SPEN's excitation and acquisition processes, a unique spin-echo is generated, which refocuses the T_2^* dephasing throughout the entire data acquisition process without the need for any *a priori* information about the field's distribution. On-going research continues to explore the use of multi-stationary-points and parallel-receive/transmit SPEN protocols in the expectation that these will facilitate high field human investigations along the lines hereby described.

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