

## Diffusion-Weighted Imaging of the Spine Using Readout-Segmented EPI and Local B<sub>0</sub> Shimming

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**Target Audience:** Radiologists, sequence developers and MR system engineers.

**Introduction:** Recent improvements in the quality of diffusion-weighted imaging (DWI) in the spine has generated an increased clinical interest in the application [1,2]. These improvements are provided by alternative diffusion-weighted acquisition schemes that can be used in place of standard single-shot, echo-planar imaging (ss-EPI). One of these techniques [3] is readout-segmented, echo-planar imaging (rs-EPI) with 2D navigator correction. This is a multi-shot EPI sequence, in which only a subset of  $k_x$  points are sampled at each excitation, allowing a substantially shorter echo spacing than is possible with ss-EPI, which results in a reduced sensitivity to magnetic field susceptibility variation. As shown previously [4], rs-EPI can be used to avoid the severe local distortions that are encountered when imaging the spine with ss-EPI. In some cases however, image quality with rs-EPI in the spine is limited by the anatomically-induced poor B<sub>0</sub> field homogeneity that typically occurs at the base of the cervical spine (c-spine). This local field perturbation can cause a failure of chemical-shift-selective fat saturation (FATSAT), resulting in an unwanted residual fat signal and even a suppression of the water signal from the spinal cord. Previous work has demonstrated that the local field variation in the brain [5] and at the base of the c-spine [6] can be reduced by using a dedicated set of local shim coils. The current study extends this work, by using local B<sub>0</sub> shimming to avoid the FATSAT errors with rs-EPI, making it possible to acquire robustly high-quality, diffusion-weighted images of the whole spine.

**Methods: MR System:** Images were acquired on a 3T MAGNETOM Skyra system (Siemens Healthcare, Erlangen, Germany) using the following receive coils: a prototype 20-channel head and neck coil; a standard 32-channel spine coil; two standard, wrap-around, 18-channel body coils.

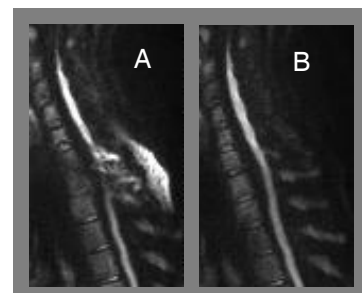
**Local B<sub>0</sub> Shimming:** The most critical point for shimming in the spine is located around the lower cervical and upper thoracic (t-spine) regions. To address this, two independent local shim-coil elements were integrated into the housing of a prototype 20-channel head and neck coil. The shim coils were constructed with 5 and 7 windings respectively and could be powered from the local coil socket using the PIN-diode drivers, allowing the shim current in each element to be controlled from the scanner console in increments of 0.1A from zero to 0.6A. The coils were equipped with series chokes to prevent coupling with the transmit (T<sub>X</sub>) and receive (R<sub>X</sub>) coils during the scan. The shape of the coils was chosen to generate a field that is tailored to the typical B<sub>0</sub> distortion determined from a volunteer study with 10 subjects of different size, age, gender and body mass index. The shim was optimized in two steps: firstly, the standard shim available on the scanner was performed and B<sub>0</sub> field maps were generated after shimming; secondly, for scans covering the c-spine and upper t-spine regions, the local shim currents were adjusted manually using information provided by the B<sub>0</sub> maps.

**Data Acquisition and Processing:** Diffusion-weighted images were acquired using a standard 2D-navigator-corrected rs-EPI sequence provided with the scanner. Separate acquisitions were performed at multiple table positions using the following measurement protocol: sagittal orientation; FOV 140mm x 200mm with 75% oversampling in the phase-encode (AP) direction; pixel size 1.4mm x 1.4mm (without interpolation); EPI echo spacing 380μs; 7 readout segments; GRAPPA with acceleration factor 2; TE 62ms; TR 2300ms; one average at a b-value of zero; three orthogonal diffusion-gradient directions with a b-value of 600s/mm<sup>2</sup>, each with three averages; 15 slices with thickness 3mm; automatic data reacquisition for scans with extreme motion-induced phase error [3]; total scan time for each table position 3:22 mins. Image reconstruction and post-processing were performed on the scanner using standard software provided with the system. The individual images from the different table positions were combined to provide composite, large-FOV spine images.

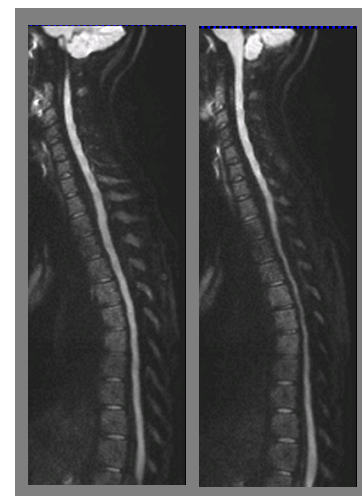
**Results:** Fig. 1A shows a trace-weighted image from the lower cervical and upper thoracic regions of the spine with a prominent artifact due to a local failure of FATSAT caused by a region of poor B<sub>0</sub> homogeneity. The signal from the cord is suppressed due to a shift in the frequency of the water resonance and obscured by superimposed, displaced signals from fat. As shown in fig. 1B, after local B<sub>0</sub> shimming FATSAT performs robustly across the whole imaging volume, providing a clear depiction of the cord. Fig. 2 shows the result of combining these locally shimmed images with images from other spine regions to generate composite, trace-weighted images of the spine with a large FOV. The composite images provide a clear visualization of the cord, together with the associated structural anatomy of the vertebral bodies and intervertebral discs.

**Discussion:** The routine application of DWI to the spine is limited by the severe field inhomogeneity that can occur at the base of the c-spine, making it difficult to achieve a robust image quality in all subjects. This study has shown how additional local shim coils can overcome this problem and enhance the quality of DW rs-EPI images. The combination of local B<sub>0</sub> shimming and the rs-EPI sequence makes it possible to perform whole-spine DWI with a low level of spatial distortion, providing a technique with potential application in a variety of clinical situations, such as the study of cord lesions [1] or the examination of vertebral body disease [2].

**References:** [1] Hayes et al. *Pediatr. Radiol.* 2012;42(8);1009-13. [2] Rumpel et al. *Eur. J. Radiol.* 2013;23(2);541-50. [3] Porter & Heidemann. *MRM* 2009;62;468-475. [4] Holdsworth et al. *ISMRM* 2009. [5] Juchem et al, *MRM* 2011 (212). [6] Biber et al. *ISMRM* 2012 (2746).



**Fig. 1:** (A) Image artifact due to a local failure of fat suppression in DW rs-EPI of the c-spine and t-spine. (B) Removal of artifact using dedicated local shim coils.



**Fig. 2:** Diffusion-weighted images of the spine using navigator-corrected, readout-segmented EPI and local B<sub>0</sub> shimming. Two adjacent slices.