Detection of Nerve Injury with Diffusion Weighted Wide Band Steady State Free Precession (DW-WBSSFP) in the Lumbar Spine

G. Danagoulian[1], R. R. Colen[2], K. Nayak[3], S. Mukundan[2], F. Jolesz[2], and E. J. Schmidt[2]
[1]Brigham and Women's Hospital, Boston, MA, United States, [2]Brigham and Women's Hospital, [3]University of Southern California

PURPOSE: Imaging of spinal pain sources may have broad public-health benefits, a result of the large prevalence of back-pain. Nerve visualization within the spinal dural sack is currently performed with MRI Myelographic sequences, such as Fast Spin Echo (FSE) and T2-weighted Gradient Echo, utilizing the strong contrast between Cerebro-Spinal-Fluid (CSF) and the nerve bundles. However, imaging of nerves outside the cord is difficult with such sequences, since they do not provide sufficient nerve-muscle or nerve-fat contrast-to-noise ratio (CNR) outside the cord, so extra-dural pain localization is difficult to perform. We previously detailed [1] a 3D Wide-Band Steady State Free Precession (WBSSFP) sequence which provided high-spatial and CNR images of spinal nerves as they pass through inter-disk foramen and muscle. This study's objective is to develop a Diffusion Weighted Wide-Band Steady State Free Precession (DW-WBSSFP) technique, which may allow both superior anatomical visualization as well as detection of nerve damage, based on diffusional signal changes in injured nerves.
METHODS: WB-SSFP (balanced to 0^{th} and 1^{st} order) [1, 2] was modified by adding diffusion gradients in multiple directions, in order to utilize the variability in spinal tissue diffusional constants to modify contrast. WBSSFP [2] alternates between a short repetition time (TRs), used to increase the SSFP acceptance bandwidth, and a long repetition time (TR), which is used for acquisition. In DW-WBSSFP, diffusion gradients were placed in TRs, somewhat elongating its length. 6 subjects, 3 healthy and 3 patients with chronic or acute spinal pain, were referred for lumbar spine studies with both conventional imaging techniques and high-resolution WBSSFP and DW-WBSSFP on a GE (Waukesha, WI) 3T Twin HDx using a CTL spine coil. WBSSFP and DW-WBSSFP were acquired in the sagittal or coronal planes, with an 18 cm FOV, centered on the spinal cord. Parameters: WBSSFP TRs=2.5-5.5ms, DW-WBSSFP TRs=5.0-5.5ms and diffusion moments of 3,000-10,000 Gauss/cm*us along the X,Y, and Z directions, TR/TE/θ=5.0-5.5ms/1.9-2.2ms/20^0 for both sequences, $\pm$41 KHz bandwidth, 80-100 slices/acquisition, 200-240 sec/acquisition. In WBSSFP and DW-WBSSFP scans, the readout direction was Superior-Inferior. Slab-selection was selectively increased to reduce breathing and wrap-around artifacts. By dividing DW-WBSSFP acquisitions with differing diffusion moments, attenuation (b*D) maps were created, where b is the diffusional moment (s/mm^2).
RESULTS: WBSSFP provided superior spinal nerve anatomy inside and outside the dural sack, and delineated nerve translation and "pinching" in all patients. WBSSFP's T_2/T_1 contrast improved the visualization of nerve fibers and ganglia against fat, bone-marrow, and muscle backgrounds. DW-WBSSFP demonstrated a signal decrease in damaged nerves (Fig. 1 B, C and Fig. 2 right), signifying enhanced diffusion, while T2-weighted FSE (Fig. 1D), with or w/o fat suppression, showed only geometric changes. No significant nerve diffusional changes were observed in healthy subjects or in the non-symptomatic nerves of patients (Fig. 2 left).
CONCLUSIONS: DW-WBSSFP provided wide-coverage, high-resolution spinal imaging with moderate (B_D~500 mm^2/s) diffusional weighting, which detected nerve injury in this limited cohort. Together with WBSSFP, it may permit detection of both anatomic changes (compression, shearing) and the extent these change cause nerve injury in the extra-dural spine.
References : [1] Schmidt ISMRM proceeding 2010, [2] Nayak KS, 2007 *MRM;58:931.*
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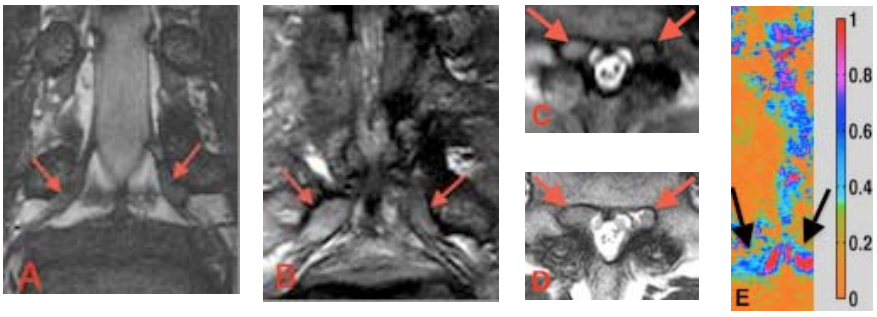

Figure 1: (A) DW-WBSSFP (diffusion moment G=10k G/cm*us, TRs=5.5ms, TR=5.5ms) shows nerve roots of a healthy subject. (B-D) 65y old woman with chronic radicular pain in the right hip with L5-S1 disk protrusion abutting and compressing the S1 nerve roots. (B) Coronal DW-WBSSFP (with diffusion moments Gx=3k G/cm*us, TRs=5.0ms, TR=6.6ms) shows L4-L5 severe bilateral foraminal stenosis and corresponding nerve roots (red arrows).
Comparison between axially reformatted DW-WBSSFP (C) and FSE (D) shows hyper-intense signal of the right ganglion versus the left ganglion, corresponding to 31% and 46% differences in DW-WBSSFP signal,respectively, between lower and higher diffusion moment DW-WBSSFP, as compared to only ~5% CNR differences relative to normal nerves in FSE (D). (E) bD map of the cord (blue) and nerve roots (black arrows) shows the larger diffusional attenuation of the nerve roots, as compared to the surrounding tissue (orange), as well as attenuation differences between the left and right injured nerve roots, whose cause is of yet undetermined.

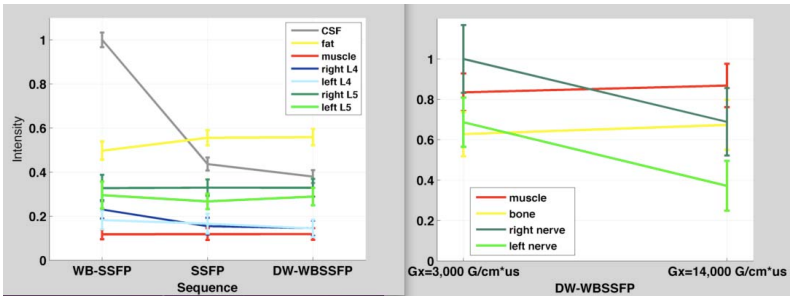

Figure 2: (Left) Signal attenuations for WB-SSFP, SSFP, and DW-SSFP, for various spinal tissues in a healthy subject. No significant attenuation due to diffusion is observed in the tissues with DW-SSFP, except in CSF, a result of its higher diffusional constant and to flow dephasing[1]. (Right) Variation of signal intensities of muscle, bone, and the two damaged nerves in the patient described in Fig.1, during an increase in diffusional moment from Gx=3k to 10k G/cm*us. The total and relative attenuation of both nerve roots are suggesting nerve injury.