Wide-Band Steady State Free Precession with Small Diffusion Gradients for Spine Imaging: Application to Superior Nerve Visualization

Ehud J. Schmidt, Ph.D.[1], Ajit Shankaranarayanan, Ph.D.[2], Sylvain Jaume Ph. D.[1,3], Giovanna Danagoulian, Ph.D.[2], Srinivasan Mukundan, Jr., M.D., Ph. D.[1], Krishna S. Nayak, Ph. D.[4]

[1]Radiology, Brigham and Women's Hospital, Boston, MA, USA, [2]GE Healthcare Applied Science Lab, Menlo Park, CA, USA [3]Computer Science and Artificial Intelligence Lab, Massachusetts Institute of Technology, Cambridge, MA, USA, [4] Electrical Engineering, University of Southern California, Los Angeles, CA, USA

PURPOSE

MRI is the most sensitive diagnostic imaging tool for patients with back pain [1]. Nerve visualization within the spinal dura is robust using common MRI Myelographic sequences, such as Fast Spin Echo and T2-weighted Gradient Echo, a result of the strong contrast between Cerebro-Spinal-Fluid (CSF) and the nerve bundles. Imaging of the nerves outside the cord, however, is difficult. Nerve tracking outside the cord is extremely important, as spinal pain frequently arises from nerve compression within the foramen, or from inflammation outside the cord [2]. Recent reports have suggested use of diffusion-weighted EPI [3] or unbalanced SSFP [4] for visualizing nerves distal to the cord, although the techniques suffer, respectively, from a low spatial resolution and high geometric distortion, or from flow-sensitivity and a low Signal-to-Noise ratio. We investigate use of high-resolution 3D Wide-Band (balanced to 0^{th} and 1^{st} order) SSFP (WBSSFP) [5] for nerve imaging outside the cord. WBSSFP may be applicable, based on its effective diffusional attenuation (B) of 40-60 s/mm^2 in the readout direction, when used with a narrow-receiver-bandwidth, as required to achieve a high-spatial resolution.

METHODS

12 subjects (6 with degenerative spine disease) had cervical spine (CS) or lumbar spine (LS) studies with both conventional imaging techniques and high-resolution WBSSFP on a GE (Waukesha, WI) 3T Twin HDX, using Zoom gradients. Conventional imaging sequences included T1- and T2-weighted 2D Fast Spin Echo in the sagittal and axial planes, as well as axial T2*-weighted RF-spoiled Gradient-Echo, acquired at 0.7x0.7x3 mm resolution. 3D WBSSFP was acquired in sagittal or coronal planes, covering a 14 cm Left to Right FOV, centered on the spinal cord. WBSSFP parameters: 0.44x0.55x1.4mm (interpolated to 0.27x0.27x0.7mm), TR/TE/θ=6.4-6.9ms/2.1-2.4ms/25^0, 2.2 ms WBSSFP Short-TR [5], ±32 KHz bandwidth, 100 slices/acquisition, 200-240 sec/acquisition. In WBSSFP scans, the readout direction was set to Superior-Inferior, generating an S/I diffusion gradient. A GE CTL spine coil was used (elements 123 for CS, 456 for LS). To track the nerve path outside the cord, curved plane reformatting (Volume Viewer, GE Advantage Windows 4.2) was performed by an experienced radiologist.

RESULTS & CONCLUSION

WBSSFP (Fig. 1) demonstrated high SNR images of C-spine anatomy. Blood-vessels had dark–lumens, while the CSF signal was more uniformly bright, as compared with T2-weighted FSE, resulting from WBSSFP's mild diffusional weighting, which dephases flowing and pulsatile spins. The high spatial resolution and strong CNR allows tracking small nerve bundles as they exit the spinal cord. Off-resonance SSFP artifacts were relatively mild, due to WBSSFP's wider pass-band. In three patients with lower back pain (Fig. 2) WBSSFP clearly demonstrated bone impingement on nerves ("nerve pinching") at points outside the spinal dura, seen due to an absence of a fatty nerve lining.

Conclusion: 3D WBSSFP provides contrast advantages for tracking spinal nerves, and may aid in diagnosing pain sources.

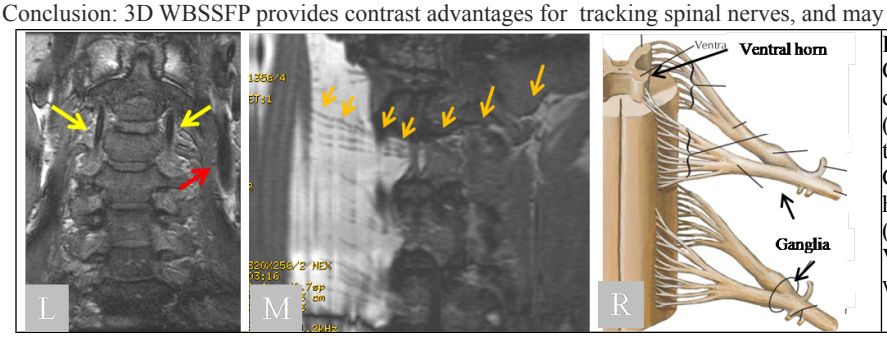

Figure 1: C-Spine WBSSFP in a normal volunteer. (L) Coronal slice of disks and vertebrae, demonstrating dark lumens of vertebral (Yellow arrow) and carotid (Red arrow) arteries, caused by diffusion-weighting in the S/I direction. (M) Curved plane reformatting tracks C2-nerve path (Orange arrows) from cord's ventral horn to ~8 cm distally. (R) Drawing of cervical nerves (Netter, Atlas of Human Anatomy), showing path from Ventral horn (in cord) outwards. Note correspondence with (M).

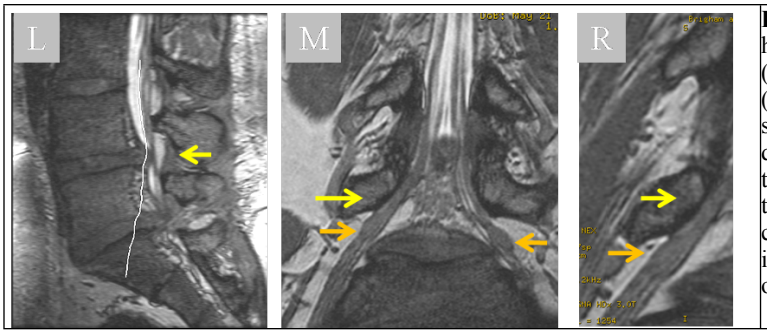

Figure 2: L-Spine WBSSFP in a patient with severe disk herniations at L4-L5 and L5-S1. Suffers from hip and leg pain. (L) Sagittal slice, demonstrating herniations and overlaid with (White) curved plane path that tracks the L5 nerve, as it exits the spinal dura. (M) Curved plane image along the White line, demonstrating pressure on the L5 nerve as it passes out through the inter-disk foramen. Note tracking of this nerve distally down to sciatic junction. Nerve ganglia (Orange arrows) are also clearly visualized. (R) Zoomed curved-plane image, showing impingement on the L5 nerve (Yellow arrow), inferred from lack of a fat layer between the nerve and the disk foramen.

REFERENCES:[[1] Gibson EG, 2003, *Evidence Based Medicine*; 8:62. [2] Boswell MV 2007, *Pain Physician*; 10: 7. [3] Takahara T, 2009, *Radiology*; 249:653. [4] Zhang ZW, 2008, *AJNR*; 29:1092. [5] Nayak KS, 2007 *MRM;58:931.*

SYNOPSIS

3D High-resolution Wide-band Steady State Free Precession (WBSSFP) is utilized to track nerves as they exit the spinal cord. By placing the readout direction in the Superior-Inferior direction, diffusional effects contribute to improved contrast between the CSF and nerves, and remove the blood signal. In several patients with degenerative spine disease, WBSSFP has aided in the diagnosis of the sources of pain.