In plane T2 mapping and diffusion tensor imaging of lumbar nerve roots using a reduced-FOV acquisition

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Introduction: Radiculopathy from nerve root irritation is common in aging patients with lumbar spondylosis, but conventional MRI has been limited to describing changes in the adjacent structures such as intervertebral disc or osteophytes that may displace or narrow the normal course of the nerve root. These indirect signs of nerve root impingement may be seen in subjects without symptoms, making it difficult to identify the specific pain generator. Advanced MR neurographic imaging techniques have been applied to visualize the lumbar nerve roots in order to depict disruption or distortion of nerve morphology [1-3]. Quantification of nerve root T_2 and diffusion values may provide an objective measure of nerve root inflammation, edema, demyelination or ischemia [4-6]. Lumbar spinal nerve roots are small structures that exit the spinal canal at an angle 30-45° to the long axis of the spinal cord and course obliquely in all 3 imaging planes (inferior, anterior and lateral), making them difficult to image [4]. We describe the application of a reduced-FOV (rFOV) technique for T_2 mapping and diffusion tensor imaging (DTI) of the lumbar spinal nerve roots in an oblique coronal plane that minimizes partial volume effects, breathing artifacts and geometric distortions.

Methods: Four healthy volunteers were scanned on a 3.0 T whole-body GE scanner using an 8-channel spine coil (USA Instruments). High- resolution sagittal T_2-weighted images were acquired using a 3D fast spin echo (FSE) sequence with fat suppression (TR/TE=2500/85 ms, ETL=120, bandwidth=62.5 kHz, 224x224 matrix size, FOV=240 mm, acquisition voxel size=1.1x1.1x2 mm^3). Next, axial and oblique coronal reformats of the FSE scan were created at the level of the L4 nerve root using maximum intensity projection (MIP) (Figs. 1a and 1b). Then, sagittal oblique reformats were created following the plane of the left L4 root (line LL in Fig. 1a) and the right L4 root (line RR in Fig. 1a). The oblique coronal plane of the nerve root was finally determined based on the axial (Fig. 1b) and oblique sagittal reformats (Figs. 1c and 1d). The determined oblique coronal plane of the nerve root (red line in Fig. 1) was used for the prescription of the center slice of the T_2 mapping and DTI sequences.

A reduced-FOV single-shot spin-echo EPI sequence was then applied using a two-dimensional RF excitation, which limits the excitation field-of-view in the phase encoding (PE) direction, for both T_2 mapping and DTI [7] (PE direction=S/I, TR=4000 ms, bandwidth=250 kHz, Nex=8, 160x42 matrix size. FOV=360x90 mm^2, acquisition voxel size=2.2x2.1x4 mm3, 15 slices). The 2D RF and 180° pulse-pair in this sequence also provide inherent fat suppression. T_2 mapping was based on the acquisition of 5 echo times between 30 and 70 ms. DTI used 24 diffusion-weighted gradient directions (b-value = 500 s/mm^2 with TE=59 ms). The overall acquisition time was 25 minutes. All parameter maps were computed using non-linear least squares fitting. ROIs were drawn on the level of dorsal root ganglia (DRG) and more distally in the spinal nerve (SPN) at both sides (left and right) of the 4 volunteers. The T_2 and DTI parameter values of the two different regions were then compared using a two-sample t-test.

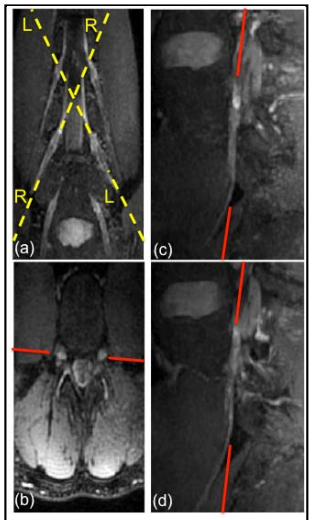

Fig. 1: L4 nerve root localization for DTI & T_2 map acquisition geometries included oblique coronal MIP reformats (a), axial reformats (b), oblique sagittal reformats of left and right nerve roots (c & d respectively) from 3D FSE data.

Results: Multiple oblique image reconstructions from the 3-D FSE sequence can be used to successfully image the lumbar nerve roots consistently in subjects (Fig. 1). T_2- and iso-diffusion-weighted images in the resulting oblique coronal plane can delineate nerve roots well from surrounding muscle due to the longer T_2 value of nerve roots relative to muscle (Fig. 2). Multiple coronal slices also allow quantification of 2 adjacent levels per acquisition targeted to a particular patient's symptoms. The low variance of the resultant T_2, mean diffusivity and fractional anisotropy values (e.g. FA=0.36±0.06) suggests this may be a reliable approach to quantification without significant contributions from partial volume effects. The visualized exiting lumbar spinal roots also can be also divided into the dorsal nerve root, dorsal root ganglia (DRG) and distal spinal nerve (SPN), although it is difficult to resolve the dorsal nerve root for quantification in the current protocol. The dorsal root ganglia have 36% higher T_2 (76±10 ms) than the distal nerve root (56±4 ms) and 39% lower FA (0.22 ± 0.04) than the distal nerve root (FA=0.36±0.06) (both comparisons, $p < 0.05$, **), as shown in Fig. 3.

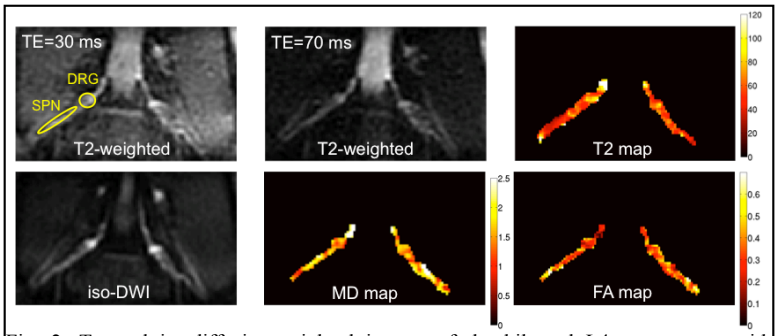

Fig. 2: T_2- and iso-diffusion-weighted images of the bilateral L4 nerve roots with subsequent maps of T_2 (units in ms), mean diffusivity (MD, units in in 10^{-9} m^2/s) and fractional anisotropy (FA, no units). Dorsal root ganglia (DRG) and distal spinal nerve (SPN) ROIs for the right nerve root are also shown.

Discussion & Conclusion: The reduced-FOV (rFOV) approach with oblique coronal image orientation enables quantification of T_2 and DTI values for lumbar spine nerve roots without significant breathing artifacts or geometric distortions. We observed higher anisotropy in lumbar spinal nerves than prior studies with axial acquisitions [4,5], more consistent with previous measurements in distal peripheral nerves [8]. This could be attributed to reduced partial volume effects from adjacent fat and muscle in the oblique coronal plane. The finding of the higher T_2 value in the root ganglia compared to the T_2 value in the distal spinal nerve is consistent with the qualitative observation that in neurographic T_2-weighted sequences the root ganglia show higher signal than the rest of the nerve. Both the higher T_2 and the lower anisotropy of dorsal root ganglia compared to the spinal nerve could be attributed to the fact that they are composed of both myelinated axons and neuronal cell bodies.

Lumbar spine pain is a complex clinical disorder. Unfortunately, conventional MRI protocols often detect multiple structural abnormalities without identifying the actual pain generator and target for therapy. Quantification of nerve root T_2 and DTI properties using this rFOV technique may allow to identify the specific site of inflammatory changes and hence pain generation and improve our understanding of the structural spinal nerve changes associated with radiculopathy.

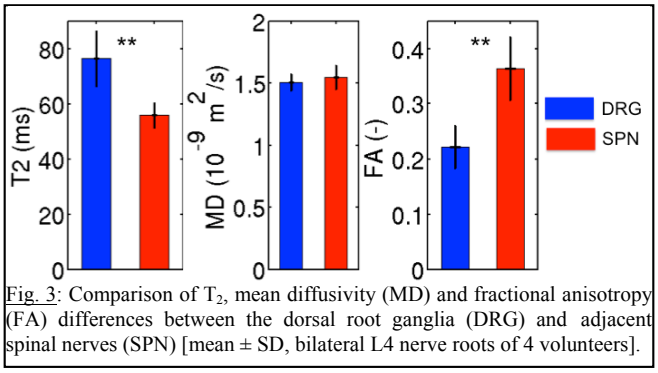

Fig. 3: Comparison of T_2, mean diffusivity (MD) and fractional anisotropy (FA) differences between the dorsal root ganglia (DRG) and adjacent spinal nerves (SPN) [mean ± SD, bilateral L4 nerve roots of 4 volunteers].

References: [1] Takahara et al., Radiology 249:653, 2008, [2] Zhang et al., Am J Neuroradiol 29:1092, 2008, [3] Shankaranarayanan et al., ISMRM 2011, p. 4410, [4] Eguchi et al., Eur Spine J 19: 1874, 2010, [5] Balbi et al. Eur Radiol 21:1153, 2011, [6] Eguchi et al., Am J Neuroradiol 10.3174/ajnr.A2681, [7] Saritas et al., Magn Reson Med 60:468, 2008, [8] Hiltunen et al, Clin Neurophysiol 116:2315, 2005.

Acknowledgement: The present work was supported by NIH-R01 AG17762.