Emerging Spine Techniques: High Field / High Resolution Spine MR

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- A range of RF engineering approaches have been explored for 7 T spinal cord MRI
- 7 T anatomical imaging with customized coils reveals unprecedented resolution
- 7 T functional contrasts (spectroscopy, fMRI, DWI) are also beginning to see benefits

I. Target Audience: Scientists / clinicians interested in spinal cord MRI at ultra-high field

II. Purpose: Technological advances in concert with guidance from clinical needs have continually improved diagnostic performance of clinical spine radiology. One route to improvement is increasing the static magnetic field strength (B_0), such as the recent generation of full-body 7.0 T scanners [1]. This survey will focus on this "ultra-high" field in the spinal cord. Since the sub-millimeter features of the cord require high spatial resolution, the enhanced signal-to-noise ratio (SNR) at high field enables advances in morphological imaging.

III. Methods: Various approaches for high field spine MRI have been demonstrated. Some achieve full spine coverage (cervical, thoracic, and lumbar) with large multi-element arrays or multiple acquisitions with a movable one. Arrays include rectangular loop coils of varying length (4 [2-5], 6 [2], or 8 [6] rostral-caudal stations) and width (1 [2], 2 [4-6] or 3 [3] left-right stations). Some arrays used the same elements for transmission / reception [2,4,5] while others used separate groups [3,6]. Localized cervical imaging studies have used a loop transmit/butterfly receive composite coil [7], a 4-ch transmit-receive cervical cradle array [8], or a 19-ch receive + 4-ch transmit composite array [9-11].

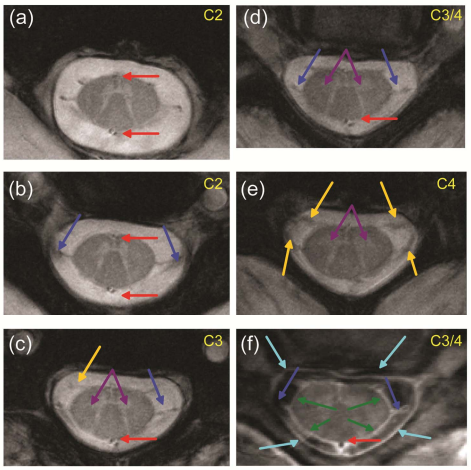

Fig. 1: C-spine MRI at 7 T. (a)-(e) GRE and (f) TSE sequence. Labels: dorsal/ventral nerve roots (yellow), gray matter anterior horn (purple), denticulate ligament (blue), dorsal/ventral blood vessels (red), dura mater (cyan), pia mater (green). (Ref. 8)

I**V. Results** Recent studies [7-9,12] have employed high resolution cervical spine imaging at 7 T to resolve gray and white matter parenchyma, which is rarely visualized at lower field. Cross-sectional white and gray matter area fractions agreed well with histological reference. Surrounding structures are also delineated with the resolution achievable at 7 T (0.2 mm, Figure 1): denticulate ligaments, nerve roots, rostral-caudal blood vessels, dura mater, and pia mater [8]. High resolution 7 T cord studies also revealed signs of localized degeneration following injury [9] and in amyotrophic lateral sclerosis (ALS) [12]. Other features in the thoracolumbosacral spine (posterior longitudinal ligament, cauda equina nerve fibers, blood vessels, common iliac artery, foramen venae basivertebralis) have also been resolved [4,6].

Beyond morphological imaging, functional contrasts in the spinal cord have also seen development at ultra-high field in full body scanners [10,13-19]. Since chemical shift-based contrast increases at higher applied field, spectroscopic techniques have been migrating successfully to the 7 T platform, including direct spectral measurement [13,14] as well as the exchange-based CEST method [15,18]. Similarly, the BOLD mechanism of functional MRI (fMRI) is also enhanced by the higher susceptibility contrast at 7 T, which has been employed in resting state fMRI pilot studies in the cord [17]. Finally, while diffusion-weighted contrast is not directly field-dependent, the higher SNR at ultra-high field may allow higher resolution DWI when combined with appropriate pulse sequences. Specifically, reduced field-of-view (rFOV) approaches that have shown promising results at lower field in the spinal cord (ZOOM [20,21],

2D pulses [22,23], OVS [24,25] , IVI [26-28]), are also finding application in some ultra-high field brain DWI studies that include the brainstem / pons [16,19]. The successful delineation of the complex structures of these areas presages possible future application of the same rFOV techniques to the spinal cord itself at 7 T.

V. Discussion / Conclusions: Pilot studies have shown the spinal cord can be visualized with unprecedented detail at 7 T, and applications to spinal cord pathologies are already beginning to emerge. Additionally, several members of the functional suite of MR contrast mechanisms are undergoing translation to the high field platform; spectroscopic and fMRI techniques in particular are demonstrating gains in sensitivity and contrast in the spinal cord area. Finally, pulse sequence adaptations continue to capitalize on the SNR gain for other contrasts like diffusion-weighted MRI. Going forward, technical and clinical imaging sectors should continue to cross-fertilize ideas to ensure the highest degree of innovation and clinical application of the high field platform for spinal cord imaging.

VI. References

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