High-resolution in vivo MR imaging of the human spinal cord at 7 Tesla

K. T. Bae[1,2], C-H. Moon[1], J-H. Kim[1], and S-H. Park[1,2]

[1]Radiology, University of Pittsburgh, Pittsburgh, PA, United States, [2]Bioengineering, University of Pittsburgh, Pittsburgh, PA, United States

[Introduction] MR imaging of spinal cord is an important component of diagnostic work-up in some diseases such as multiple sclerosis (MS). In MS, the spinal cord is frequently involved and often in combination with lesions in the brain. In some MS cases, lesions have been found to involve only the spinal cord, particularly in the cervical spinal cord. Compared to brain imaging, spinal imaging is more challenging because of the regional complex structures of the spine and intrinsic cord motion [1]. MR evaluation of the spinal cord has also lagged behind imaging of the brain, in part due to limitations of surface coils and imaging techniques [2]. Recent technical advances in MR imaging may facilitate not only the accurate detection but also the characterization of spinal cord lesions by location and imaging features. In particular, ultra-high-field MR imaging provides high SNR that improves visualization of spinal cord with high-resolution and enhanced tissue contrast. The purpose of this study is to demonstrate the feasibility of high-resolution in vivo 7 T MR imaging of human spinal cord using a newly developed surface RF coil and imaging techniques.

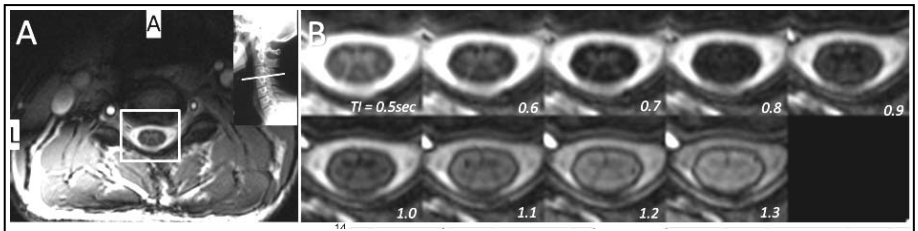

Fig. 1 (A) T1-w IR-MPRAGE cervical spine image at C3-4 level. (B) Series of IR images (white-box in A) with varying TI from 500 to 1300 ms at 100 ms interval.

[Methods] All imaging was performed on 7T human MR scanner (Siemens Medical System, Erlangen, Germany) with in-house surface RF coil designed for imaging of cervical spinal cord. The conductor loop of c-spine RF coil consisted of a butterfly-shaped coil and a smaller inner oval coil to generate the quadrature field for the deep penetration of RF power. Three normal volunteers were scanned. Shimming and RF power were adjusted for the spinal cord region. Of available pulse sequences for spinal cord imaging, we chose T1-weighted inversion recovery sequence, because this sequence was reported superior to other sequences for depiction of cervical spinal cord lesions in MS [3]. A fast gradient-echo sequence such as MPRAGE is useful to reduce motion artifact from respiration and CSF flow in the cervical spine. The MR parameters of 2D T1-weighted IR-MPRAGE sequence were; TR/TE = 6.0/2.7 ms, in-plane resolution = 500 × 500 μm^2, slice thickness = 3.5 mm, flip angle = 12°, bandwidth = 200 Hz/pixel, linear phase encoding, average = 10, time between two consecutive IR pulses = 6 s, and total scan time = 1 min. To assess the effect of inversion time (TI) on spinal gray (GM) and white matter (WM) differentiation and tissue-conspicuity, a series of spinal cord images were acquired by varying TI = 500 – 1,300 ms at 100 ms interval. The images with the maximum suppression of GM or WM were determined from the series of variable TI images. To maximize the GM-WM tissue contrast, we computed two ratio images: WM-enhanced ratio image (i.e., the ratio of the maximum-suppressed GM to the maximum-suppressed WM images) and GM-enhanced ratio image (i.e., the ratio of the maximum-suppressed WM to the maximum-suppressed GM images). These enhanced and original T1-w images were compared for depiction of spinal cord and GM-WM differentiation.

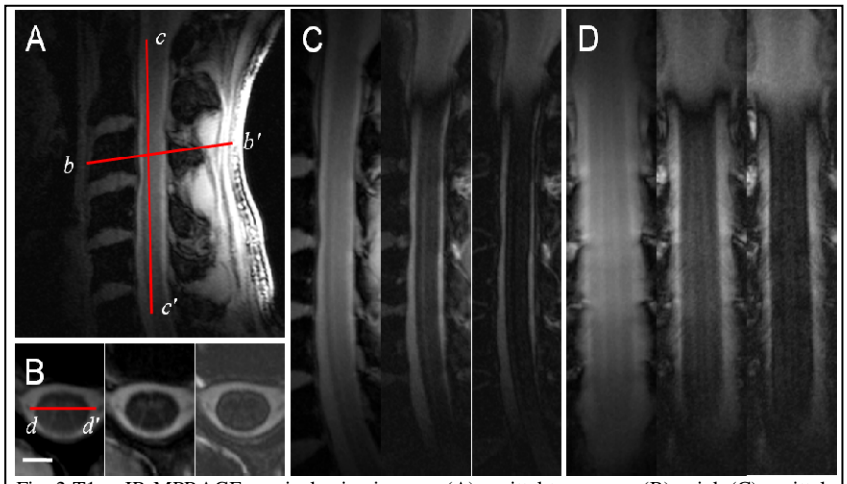

Fig. 2 T1-w IR-MPRAGE cervical spine images: (A) sagittal topogram, (B) axial, (C) sagittal, and (D) coronal spinal cord images with non-inversion, TI 500, and 900 ms. Scale bar 10 mm.

[Results and Conclusions] The T1-w images depicted high-resolution cervical spinal cord structures with high SNR. Excellent GM-WM differentiation was observed on axial images (Fig. 1). The characteristic H-shaped GM in the center surrounded by the WM was clearly visualized on the cervical spinal cord images. While preserving high-sensitivity, the effective RF penetration of our spine coil sufficiently covered the entire cervical spinal cord (approximately ~50 mm), as shown in multi-planar spinal cord images acquired with no-inversion, TI 500, and TI 900 ms (Fig. 2).

The tissue-contrast of GM and WM varied with TI (Fig. 1). The bright contrast of GM relative to WM declined with increased TI. The bright and dark intensities of WM and GM reversed around TI = 800 ms. While the WM was suppressed around TI = 500 – 700 ms, the GM around 900 – 1000 ms for given MR parameters of the study. The GM- and WM-enhanced ratio images were obtained by taking the pixel-by-pixel ratios of the GM and WM suppressed images (Fig. 3). The enhanced ratio images increased tissue-contrast ranges within the GM and WM and improved depiction of some small structures such as median septa that were not discernible on the original T1-w image (Fig. 3D). These enhanced features may assist the localization and characterization of MS spinal cord lesions. Our on-going research includes the optimization of MR parameters and spinal cord imaging of MS patients.

In conclusion, high-resolution in vivo imaging of human spinal cord was feasible using an appropriately designed surface RF coil at 7T. The GM and WM of the cervical spinal cord were well depicted on the T1-w IR images and differentiated better on the enhanced GM and WM imaging.

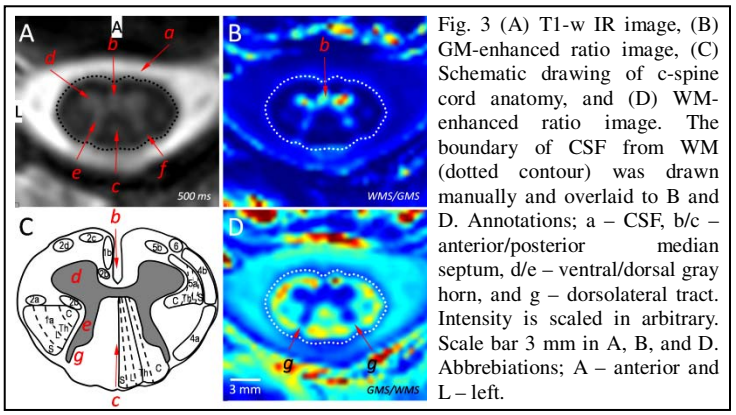

Fig. 3 (A) T1-w IR image, (B) GM-enhanced ratio image, (C) Schematic drawing of c-spine cord anatomy, and (D) WM-enhanced ratio image. The boundary of CSF from WM (dotted contour) was drawn manually and overlaid to B and D. Annotations; a – CSF, b/c – anterior/posterior median septum, d/e – ventral/dorsal gray horn, and g – dorsolateral tract. Intensity is scaled in arbitrary. Scale bar 3 mm in A, B, and D. Abbrebiations; A – anterior and L – left.

[Reference] 1. Ge, AJNR 27:1165–76 (2006). 2. Tartaglino et al., Radiology 195:725-732 (1995). 3. Poonawalla et al, Radiology 246:258-264 (2007)