Measuring Cross Sectional Area of the Spinal Cord at 7T: Validating Fully Automated Segmentation

Benjamin N Conrad[1], Bailey D Lyttle[2], Siddharama Pawate[3], Robert L Barry[1,4], Bennett A Landman[1,5], and Seth A Smith[1,4]

[1]Vanderbilt University Institute of Imaging Science, Nashville, TN, United States, [2]Neuroscience, Vanderbilt University, Nashville, TN, United States, [3]Neurology, Vanderbilt University, Nashville, TN, United States, [4]Radiology and Radiological Sciences, Vanderbilt University Medical Center, Nashville, TN, United States, [5]Electrical Engineering, Vanderbilt University, Nashville, TN, United States

Purpose

Spinal cord atrophy is a clinical symptom associated with many diseases, including multiple sclerosis (MS), as well as in acute spinal cord injury. Cross sectional area (CSA) of the cervical spinal cord at the C2/C3 junction is the most commonly reported measure of cord atrophy and is consistently found to be negatively correlated with disability[1]. Measurement of CSA typically involves either manual or semi-automated segmentation. Manual segmentation is time-expensive and subject to operator bias. Semi-automated techniques currently represent the gold standard but are similarly constrained by the need for user input[2]. Advances in image acquisition and segmentation methods are converging to allow for reliable, fully automated techniques for assessing CSA[3,4]. The current analysis compares a recently developed automatic labeling scheme using T2*-weighted images to a standard, semi-automated procedure using T1-weighted images. The latter will serve as "ground truth" measurements of CSA in order to validate the T2*-w estimations.

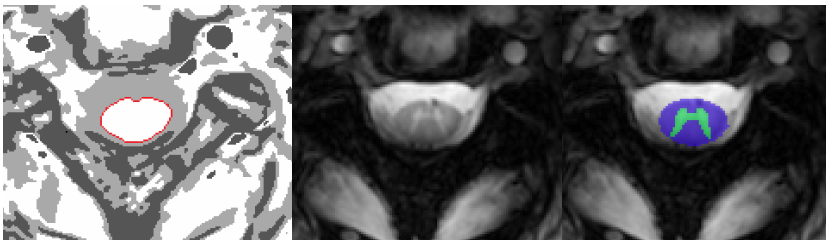

Figure 1: *"Ground truth" estimation from T1-w segmentation (left). T2*-w anatomical image from same subject (middle). Automatically labelled cord (right), green=GM, blue=WM.*

Methods

T1- and T2*-weighted anatomical images were acquired in succession with the same slice geometry on a Philips 7T Achieva scanner using a custom 16-channel Nova cervical spine coil and the following parameters: T1 - 3D fast-field echo (FFE), TR/TE/flip angle = 30ms/4ms/60° and T2* - multi-slice FFE, TR/TE/flip angle = 305ms/9ms/25°. CSA was measured in two groups: 20 patients with relapsing-remitting MS and 18 healthy controls. An axial slice was chosen in the C2/C3 level for each subject and the corresponding T1- and T2*-w images were analyzed separately using the techniques described below. A comparison of the final CSA estimates is plotted in Figure 2.

T1-weighted semi-automated segmentation:

A volume of interest was defined around the spinal cord and cropped inclusively. Optimized N3 bias correction was performed in MIPAV to remove spatially varying intensity inhomogeneities. The flattened image was segmented with FSL's FAST tool and the output was used to estimate area of the cord in mm^2.

T2-weighted automated segmentation:*

A set of 1538 3T cervical slices from healthy controls was previously labelled and incorporated into a multi-atlas label fusion model. The technique was published and described in depth by Asman et al (2014). Segmentation was performed in MATLAB on raw, uncorrected T2*-w axial images. Each axial slice took approximately one minute to label. Voxels within the gray and white matter masks were automatically counted and summed to acquire CSA.

Results

Figure 2 presents CSA measurements for RRMS patients (left panel) versus healthy controls (right panel). Overall, HC demonstrate higher CSA than RRMS. In HC, T2*-w segmentation overestimates CSA by 14.0 ± 4.3 mm^2 in comparison to the T1-w method. In the patient group, CSA is overestimated by 14.0 ± 5.7 mm^2 compared to the T1-w method. The higher variance in the patient group may be in part due to higher variability in the MS cords (e.g. due to lesions) and/or noisier images related to movement.

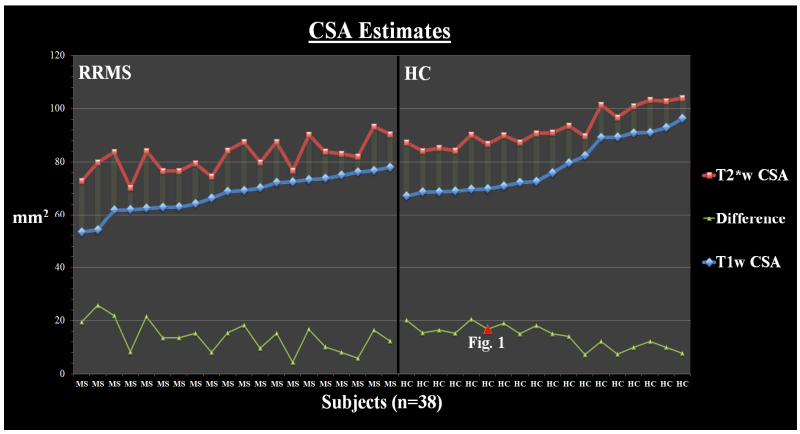

Figure 2: *Comparison of cross sectional area derived from corresponding T1-w and T2-w slices. Results are ordered in each group from smallest to largest according to T1-w CSA.*

Discussion/Future Directions

The present analysis demonstrates the successful use of multi-atlas label fusion to automatically calculate CSA from T2*-w images at 7T, achieving a strong relationship with our "ground truth" T1-w estimations. The effective use of a 3T label set on 7T target images suggests that label fusion is robust across scanning parameters, field strength and preprocessing techniques. The method may be especially useful in labelling the relatively simple, albeit variable, structures of the spinal cord. While not shown here, the 2D segmentations can easily be expanded to assess whole cord volume and gray/white matter volumes individually or average CSA across a cord segment. The development of a 7T label set is already underway and should improve reliability of the model**.** The automatic technique used here not only provides gross cord information but also differentiates gray and white matter. This is potentially useful for co-registration of the spinal cord, including analyses of fMRI, MT, and CEST imaging. One future direction for this work is to utilize multi-atlas segmentation and the recently released MNI-Poly-AMU spinal cord atlas by Fonov et al for normalization into a group space[5].

References

1. Bakshi R.; et al. *J Neuroimaging* 15(4), (2005). 2. Cohen-Adad J. & Wheeler-Kingshot C. (Eds.). *Quantitative MRI of the Spinal Cord*. Elsevier (2014). 3. Sigmund E.E.; et al. *NMR Biomed* 25(7), (2012). 4. Asman A.J.; et al. *Medical Image Analysis* 18, (2014). 5. Fonov V.S.; et al. *NeuroImage* 102, (2014).

Acknowledgments

Novartis IIRP-1456