Rapid Semi-Automatic Segmentation of the Spinal Cord from Magnetic Resonance Images

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Introduction

Spinal cord atrophy is a feature of multiple sclerosis (MS) and is a putative outcome measure that may be useful in assessing the effects of emerging neuroprotective therapies (*1*). However, there is still a need for a fast, reliable post processing method to assess spinal cord atrophy from MRI scans, since the rate of atrophy is only on the order of 1% per year in the relapsing-remitting form of MS (*2*). We demonstrate a new highly-reproducible method of spinal cord segmentation, and show that it can be used to extract the cord surface from the foramen magnum to its inferior terminus.

Method

The method is based on an active surface (AS) model, with a compact parametrization that specifies the center-line of the cord, and a radius generator. The center-line generator is implemented as cubic spline interpolators of the x and y location of the cord center at the slice centers and is initialized by the user, who clicks on the approximate cord center on a few representative slices. The radius generator is initialized with a constant radius, and is updated according to the local image intensity gradient vector near the cord surface according to a function that is minimised when the vector normal to the active surface is parallel to the intensity gradient vector.

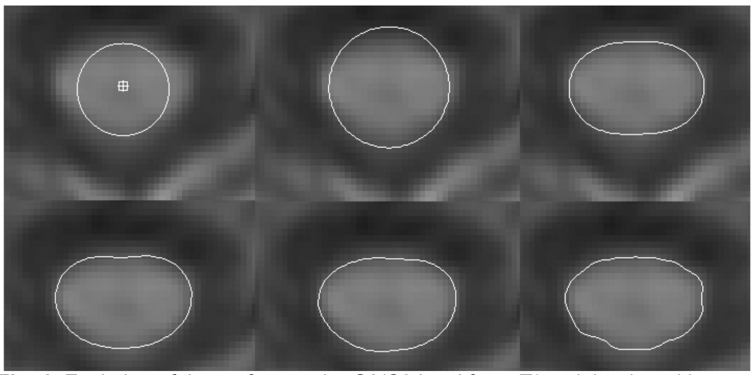

Fig. 1. Evolution of the surface at the C2/C3 level for a *T*1-weighted cord image.

The method can be used with either *T*1- or *T*2-weighted images, where the cord is either hyper- or hypointense to the surrounding CSF. The cord radii are then constrained to vary smoothly, both around the cord and along the cord by a low-pass filtering and interpolation procedure. In a 2-stage iterative update process, the center-line is also constrained to follow a smooth path close to that specified by the user during initialization. Surface evolution uses a multi-scale approach, with steadily decreasing smoothness constraints at each scale.

Processing time is on the order of 2 minutes for a whole-cord segmentation. The method was tested by assessing the intra- and inter-operator reproducibility on a sample of 60 *T*1-weighted images from MS patients and normal controls, comparing these to another highly-reproducible method that can be used to segment the cord at the C2/C3 disk in the cervical region (*3*).

We also show a novel form of cord visualization, in which the cord center-line forms one coordinate axis of a new image. The original image is resampled in planes that are always perpendicular to the center-line at regular distance intervals along the centre-line coordinate. This allows easy visualization of the cord structure and pathology.

Results

The Table shows the mean cord areas measured by three observers, together with the intra- and inter-observer coefficients of variation. Results for the AS method are shown for a short segment of cord at the C2/C3 level for direct comparison with the Losseff method, and over an extended cervical cord region from C2 to C5.

	Observer 1	Observer 2	Observer 3	Intra-Observer CoV	Inter-Observer CoV
Losseff method C2 area / mm^2	66.01	59.65	68.35	2.15 %	7.95 %
AS method C2 area / mm^2	75.26	75.41	75.55	0.59 %	1.36 %
AS method C2-C5 area / mm^2	78.42	78.27	77.57	0.44 %	1.07 %

The reproducibilities for the AS method compare favorably with those of the Losseff method, but the estimated areas are greater by approximately 13%.

Fig. 2 shows a *T*2-weighted image in which the cord has been segmented and the image resampled, with the centre-line parameter forming the *z*-coordinate of the new image. The original image was collected in 3 slice blocks, with table movement between blocks.

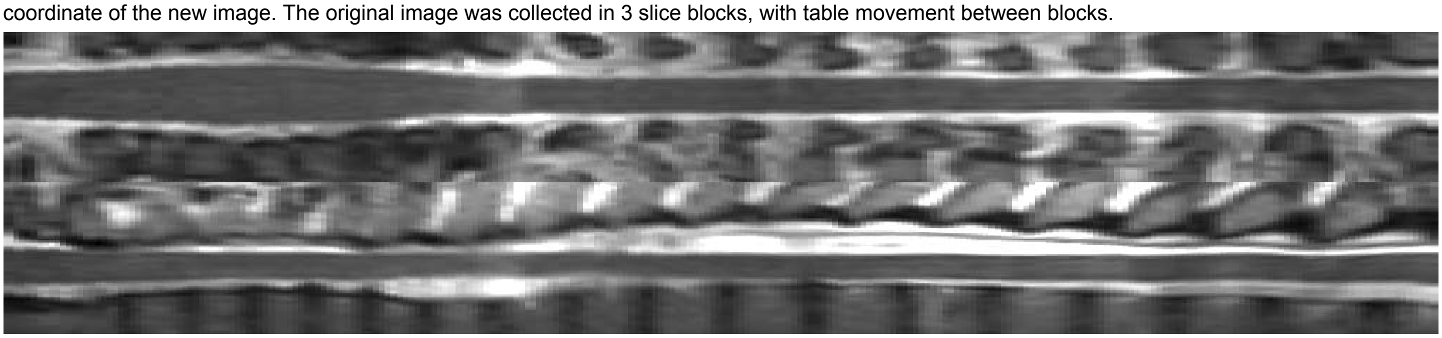

Fig. 2. Straightened cord image in coronal (top) and sagittal (bottom) views.

Conclusions

We have demonstrated a rapid and highly-reproducible method of spinal cord segmentation that requires only minimal user interaction. The parametrization of the centre-line allows a novel method of cord visualization that may find utility in wider radiological practice.

References

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