RAPID SEGMENTATION OF THE CERVICAL SPINAL CORD ON 3D MRI DATA WITH CORD IMAGE ANALYZER (CORDIAL): APPLICATION TO THREE-YEAR FOLLOW-UP DATA OF MS PATIENTS WITH A PROGRESSIVE DISEASE COURSE

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Introduction

MRI of the spinal cord (SC) is a valuable part of the diagnostic work-up in multiple sclerosis (MS) patients. Due to its critical role for locomotion, the SC is considered as an area of great importance in MS, and SC atrophy is a frequent feature of MS even at early stages of the disease [1]. In this work, we present an automated method for segmenting the SC in 3D MR data. The "*cord image analyzer (cordial)*" provides volume measurements for SC sections of fixed length and location in a primarily automated way. Reliability of *cordial* was tested on volunteer scans and follow-up data of a cohort of 48 MS patients was evaluated with *cordial* to assess the relation between cervical SC atrophy and clinical outcomes.

Methods and Subjects

Cordial pre-segments the SC based on manually placed seed points, i.e. two small sets of voxels marking both the SC and the background. The pre-segmentation uses the continuous max-flow approach [2], increasing its robustness by adding a cross-sectional similarity prior [3]. The SC surface is subsequently reconstructed by locating the exact SC boundary based on the image intensities [4]. In this work, cutting planes perpendicular to the SC centerline were defined 25 mm and 75 mm inferior to the cisterna pontis (Fig.1) and the cervical SC volume (CSCV) was calculated for the 50 mm SC segment in-between. Cisterna pontis location was determined by a manually placed landmark.

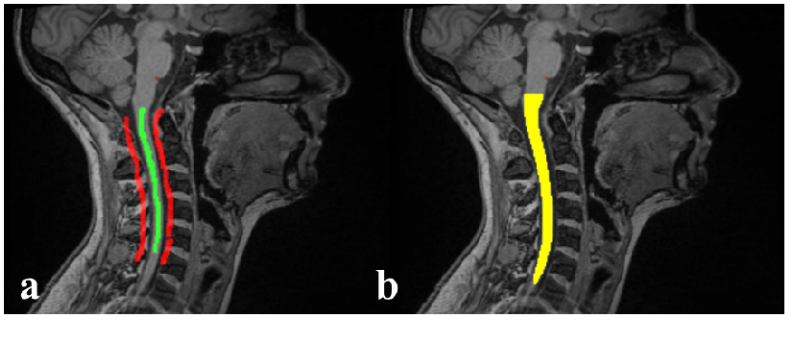
To assess the reliability of *cordial*'s SC segmentation, 17 healthy controls (HC, 7 women, mean age 32.5 y, range 24–47 y) were scanned on a 3 T whole-body MR scanner (Verio, Siemens Medical, Germany) with a T1-weighted MPRAGE sequence (TR/TI/TE/α= 2.0 s/1.0 s/3.4 ms/8°); 192 sagittal slices parallel to the interhemispheric fissure were acquired with an isotropic resolution of 1mm^3. The acquisition time for the MPRAGE was 4:08 min (ipat = 2). Each scan was repeated three times: between the 1st and the 2nd scan, the HC remained in the scanner, before the 3rd scan, HC left the scanner and were then rescanned. Coefficients of variation (COV) were calculated for scan–rescan reliability as well as for intra- and inter-rater reliability. To evaluate the latter, *cordial* was applied twice to the data by two experienced scientists. To show the applicability to clinical data, we used follow-up data of 48 patients with a progressive course of MS [24 women, mean age 52.1 y (range 22–67 y), median disease duration 14.0 y (range 1–47 y), median EDSS 4.5 (range 2.5–6.5)]. 30 patients had a secondary progressive (SPMS) disease course, 18 patients had primary progressive MS (PPMS). The patients were scanned on a 1.5T whole-body MR scanner (Avanto, Siemens Medical, Germany) with a MPRAGE sequence (TR/TI/TE/ = 2.08 s/1.1 s/3.93 ms/15°); 160 sagittal slices were acquired with an in-plane resolution of 0.98x0.98 mm^2 and a slice thickness of 1 mm. Scans were acquired at two time points approximately 3 years apart (mean follow-up 3.1 y, range 2.9–3.6 y).

Results

Mean CSCV of the HC was 3880 mm^3 (range 3088 mm^3-4589 mm^3). The scan-rescan COV as well as the intra- and inter-rater COV of the segmentations are listed in Tab. 1&2. The CSCVs of the MS patients (mean±SD) are summarized in Tab. 3. We did not observe significant CSCV differences between PPMS and SPMS at either of the two time points. However, the volume loss per year was by trend higher in PPMS (p=0.05). To reveal correlations between clinical outcome parameters and cervical SC atrophy, we conducted a multiple linear regression analysis with EDSS change over three years as dependant variable and demographic factors (age, disease duration and course, and gender) and CSCV loss as independent variables. In this model, CSCV atrophy was the only significant predictor of EDSS change (p=0.02).

Discussion

In this work, we demonstrate that *cordial* allows rapid SC segmentation with high reliability. Applying *cordial* to MRI data of MS patients with progressive disease course, we found borderline significant differences in CSCV loss between PPMS and SPMS and a significant correlation between CSCV atrophy and EDSS change over three years.



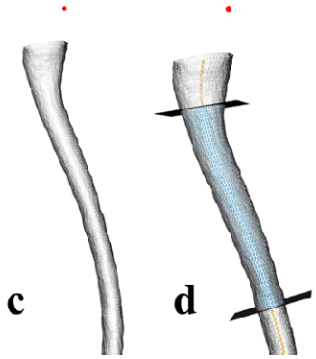


Fig. 1: SC segmentation with *cordial.* a: Manual intervention is only needed for seed point definition (green: SC, red: background); b: SC pre-segmentation (yellow); c: SC surface reconstruction; d: definition of cutting planes for CSCV calculation. The red dot depicts cisterna pontis which serves as anatomical landmark.

scan-rescan COV (%)	scan#1-scan#2	scan#1-scan#3
rater #1, run#1	0.48	1.02
rater #1, run#2	0.74	0.93
rater #2, run#1	0.57	1.00
rater #2, run#2	0.48	0.87

Tab. 1: Coefficients of variation (COV) for scan-rescan reliability. Between scan#2 and scan #3, HC were repositioned.

intra-rater CoV (%)	run#1-run#2
rater #1	0.42
rater #2	0.29
inter-rater COV (%)	rater#1- rater#2
run#1	0.37
run#2	0.36

Tab. 2: Coefficients of variation (COV) for intra- and inter-rater reliability.

CSCV (mm^3)	BL	FU	volume loss per year
all patients	3195±491	3138±503	18.9±38.0
PPMS	3220±563	3122±605	32.7±45.8
SPMS	3180±452	3147±443	10.68±30.5
p-value	0.8	0.9	0.05

Tab. 3: Cervical spinal cord volume (CSCV, mean±SD) for PPMS and SPMS patients at baseline (BL) and after three years of follow-up (FU).

References

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