IMPROVED ACQUISITION STRATEGY FOR CORD AREA MEASUREMENT WITH 3D-T1W PHASE SENSITIVE INVERSION RECOVERY (PSIR)

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INTRODUCTION: A reduction in cord volume can be seen as a result of many pathological conditions affecting the spine. In multiple sclerosis (MS), for example, a reduction in the mean cross-sectional area of the cervical cord over time indicates the presence of cord atrophy, which correlates with neurological disability [1]. The mean cross-sectional area of the cord has traditionally been measured from MR images by means of image segmentation. Typically, a 3D-T1W volume scan is acquired in the sagittal plane with isotropic voxel size and the mean cross-sectional area is measured from axially reformatted images of a 15 mm section of the cervical cord at the level of C2-3 intervertebral disc. While post-acquisition image segmentation methods have improved considerably over the years (published coefficients of variation (COV) of 0.42%-2.15%) [1-3], very little has been done to improve the image acquisition protocols. In this study, it is hypothesised that the use of phase sensitive inversion recovery (PSIR) reconstruction [4] in combination with the most commonly used 3D-T1W pulse sequence may result in improved segmentation of the cervical cord if used with existing image segmentation methods because of the extended dynamic range of the images. The proposed imaging protocol is optimised initially in a pilot study with the use of a phantom and subsequently evaluated in a number of healthy control volunteers.

METHOD: Optimisation study: In order to optimise the imaging protocol, a phantom was constructed to simulate the cervical cord and the surrounding cerebrospinal fluid (CSF). This was made of a solid acrylic rod of diameter 76.9 mm^2 that was immersed in distilled water. In this way, an interface between MR signal (water) and signal void (acrylic rod) is created providing a well defined border for testing the effectiveness of segmentation [5]. Using a 3T Philips Achieva MRI system with RF multi-transmit technology (Philips Healthcare, Best, Netherlands) and the 16-channel neurovascular (NV) coil, the phantom was imaged in the axial plane (i.e. slices perpendicular to the acrylic rod) using a conventional 3D-T1W pulse sequence with and without the selection of PSIR. The following protocol was acquired: (a) conventional 3D-T1W TFE with voxel size 1 x 1 x 1 mm^3, TR = 8 ms; TE = 3.7 ms; flip angle $\alpha = 8°$; FOV = 256 x 256 mm; NEX = 1; 128 slices, total scanning time = 6:31 min; b) same sequence and protocol as in a) with the addition of PSIR (flip angle of $\alpha = 5°$); scanning time was 13:04 min; c) the same 3D-T1W TFE pulse sequence as in a) but with a voxel size of 0.5 x 0.5 x 3 mm, TR = 12 ms; TE = 6.1 ms; flip angle $\alpha = 8°$; FOV = 512 x 256 mm; NEX = 3; 19 slices and scanning time = 7:10 min; d) the same sequence as in c) with the addition of PSIR, (flip angle $\alpha = 5°$) and all other parameters kept the same as c); the scanning time was 14:22 min. In order to assess the scan-rescan reproducibility of the imaging protocol, the same phantom was imaged 3 times on 3 separate occasions. Image analysis was performed using JIM (Xinapse systems, www.xinapse.com); a 15 mm section positioned at the center of the phantom was extracted according to standard in vivo protocols and analysed based on an active surface model of the cord surface [2]. For the assessment of scan-rescan reproducibility, the coefficient of variation (%COV) was calculated using the mean and standard deviations from the repeated measures using the equation COV=100 x [SD/mean]. In-vivo study: five healthy control subjects were recruited (mean age 29 years, range 27-31, 4 male, 1 female) and imaged with the imaging protocol that had the highest reproducibility, as identified from the pilot study. Informed consent was obtained from all participants and the study was approved by the local institutional review board. Scan-rescan reproducibility was assessed by repeating the MR imaging protocol 3 times on all 5 volunteers, on separate occasions (with a minimum of 7 days and a maximum of 14 days interval between measurements), and with one rater analysing all the data. In order to assess the intra-observer reproducibility, the same rater re-analysed all the data after a period of at least 2 weeks. The inter-observer reproducibility was assessed with the participation of one more rater, who was unaware of the results of the first rater. For the assessment of scan-rescan, intra- and inter-observer reproducibility, the coefficient of variation (%COV) was calculated.

RESULTS: Optimisation study: The mean cross-sectional area of the 15 mm section of the phantom acquired with the 3D-TFE T1W and 1 x 1 x 1 mm^3 voxel size was 80.7 mm^2 without the use of PSIR (scan-rescan COV, 1.38 %) and 81.7 mm^2 with the use of PSIR (COV, 0.8 %). The mean cross-sectional area of the 15 mm section acquired with the 3D-TFE T1W using 0.5 x 0.5 x 3 mm^3 voxel size was 79.7 mm^2 without the use of PSIR (scan-rescan COV, 1.17 %) and 82.2 mm^2 with the use of PSIR (COV, 0.37 %). In-vivo study: The results from the optimisation study showed that the combination of 3D-T1W and PSIR using 0.5 x 0.5 x 3 mm^3 resolution offered the best reproducibility for the mean cross sectional area and was subsequently used to image all healthy controls. Figure 1a) shows an example of an image acquired through the C2-3 intervertebral disc of a healthy control using the optimised sequence with PSIR. Figure 1b) shows the same slice of figure 1a) without the use of PSIR. The mean cross-sectional area measured in 5 controls was 86.26 mm^2 and the mean scan-rescan, intra- and inter-observer COVs were 1.03%, 0.07% and 0.4%, respectively. Table 1 shows a breakdown of the results for each study participant individually.

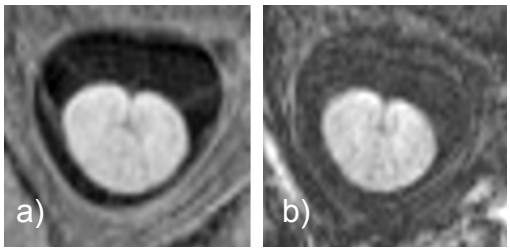

Figure 1 - a) Axial 3D-T1W TFE with PSIR and resolution 0.5 x 0.5 x 3 mm^3 through the C2-3 intervertebral disc and b) the same slice acquired with the same sequence parameters and resolution but without PSIR. Note: both images are displayed with the same windowing intensity range.

Table 1	Scan 1 (mm^2)	Scan 2 (mm^2)	Scan 3 (mm^2)	Scan-rescan (%COV)	Intra-observer (%COV)	Inter-observer (%COV)
Case 1	94.9	95.9	95.5	0.53	0.09	0.06
Case 2	71.8	70	71.8	1.44	0.02	0.26
Case 3	82	80.4	80.6	1.04	0.08	1.14
Case 4	87.9	85.7	86.7	1.26	0.04	0.17
Case 5	94.7	94.6	93.2	0.86	0.11	0.37

CONCLUSION: A new MR acquisition protocol has been presented, which utilises PSIR in combination with conventional 3D-T1W for high resolution imaging of the cervical cord. The images obtained have been shown to enable segmentation of the mean-cross sectional area of a 15 mm section of the cervical cord in 5 control cases with cord area comparable to existing methodologies, plus the additional benefit of highly reproducible measurements [1-3]. Future investigations will be evaluating the acquisition protocol presented here in disease state and, if the high reproducibility is confirmed, cord atrophy measured with this methodology could become a feasible and clinically relevant biomarker.

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