3D Myelin Water Imaging of Cervical Spondylotic Myelopathy at 3T

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Introduction

Cervical spondylotic myelopathy (CSM) is the leading cause of spinal cord dysfunction in people over 55 years of age in North America, and is characterized by a narrowing of the spinal canal leading to cord damage. Although conventional MR imaging of CSM is effective at identifying levels of stenosis and ischemia, T_2 weighted images do not elucidate the specific pathological processes, such as demyelination, that affect the grey and white matter[1]. Furthermore, the relationship between stenosis and the demyelination that leads to CSM symptoms is poorly understood. An exciting technique which may prove to be more sensitive to changes in the spinal cord is multi-echo T_2 relaxation, which allows the amount of myelin in a given region to be determined by analyzing T_2 relaxation distributions. The relative contributions from water in different environments can be resolved through analysis of the T_2 decay curves (in particular the water trapped between the myelin bilayers, with $T_2 < 40$ ms)[2,3]. The ratio of myelin-associated water to the total water present provides a quantitative measure of the myelin water fraction (MWF), which has been shown to correlate strongly with luxol fast blue staining for myelin indicating that MWF is a surrogate marker for myelin[4]. Through this present study, we sought to clearly identify changes in MWF in dorsal column white matter to detect demyelination as a possible cause of spinal cord dysfunction in regions of stenosis.

Methods

Subjects: Ten healthy adults (6 female, 4 male, mean age 25y, range 22-30y) and six subjects diagnosed with CSM as characterized by established clinical deficits (1 female, 5 male, mean age 58.6y, range 50-62y) were recruited from the Vancouver Spine Program, as well as one age matched control (male, 60y).

MR Experiment: Subjects were scanned on a 3.0T system (Achieva, Philips Medical Systems) with a phased array spine coil using only the first four channels. Multi-echo T_2 relaxation was performed using a 3D 32 echo modified Carr-Purcell-Meiboom-Gill sequence consisting of a 90° slice selective pulse followed by 32 slab selective 180° pulses (first echo at 10ms, echo spacing of 10ms, TR=1300ms, eight 5mm thick axial slices perpendicular to the spinal cord, 256×128 matrix, FOV 180mm×135mm, single acquisition)[5]. The volume of interest was centered at the C5 vertebra in healthy subjects and at the level of stenosis, or centre of multiple stenosis levels, in CSM subjects and the matched control.

Data Analysis: The first and eighth slices were discarded due to aliasing along the slice selective direction, and in most subjects an additional one or two slices were discarded due to phase wrap artefact that overlapped with the spinal cord signal. Scans from two male subjects (one healthy adult, one CSM subject) were discarded due to phase-wrap artefact in all slices. The 32 echo decay curve for each pixel was decomposed into an unspecified number of exponentials using a regularized non-negative least squares algorithm with 120 input relaxation times spaced logarithmically from 15ms to 2s[3]. Both χ^2 and solution roughness were minimized such that χ^2 fell between 1.02 and 1.025 times the minimum χ^2 from the non-regularized least-squares solution[3]. The MWF was defined as the fraction of the T_2 signal between 15 and 40ms relative to the total T_2 signal, and a myelin map was produced by displaying the MWF for each pixel in the spinal cord (see Figure 1). An ROI was drawn well within the dorsal column white matter on MWF maps. All errors are expressed as standard errors.

Results

Myelin maps often show the characteristic butterfly distribution between grey and white matter in the spinal cord (Figure 1: B1). This butterfly pattern sometimes became indistinguishable at levels of stenosis in CSM patients (Figure 1: D 3,4). The significant difference between MWF in CSM subjects compared to healthy adults (Table 1) is consistent with the expected demyelination of the dorsal columns, however, changes in total water content caused by inflammation or edema could also contribute to decreased MWF. The lack of significant variation in MWF across slices implies that the pathology is not limited to the level of stenosis (Table 1 & Figure 2). More CSM subjects are needed to confirm these findings, as well as age matched controls to eliminate any age dependence in MWF values.

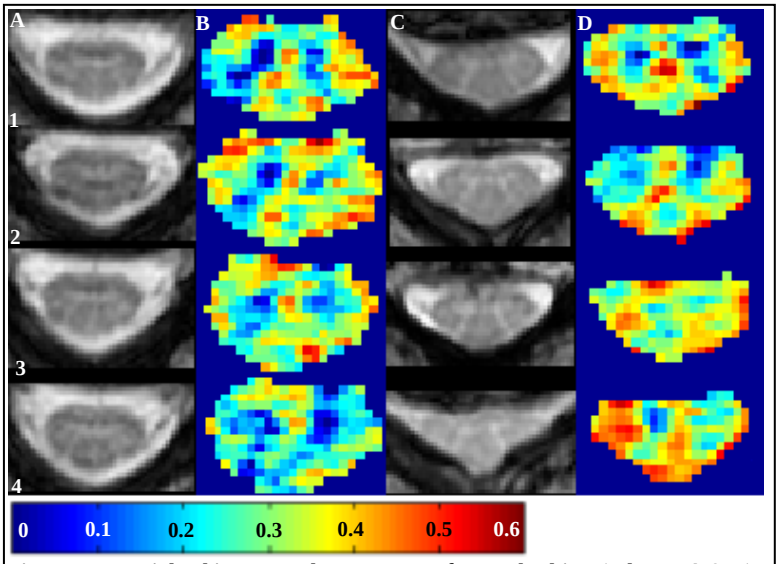

Figure 1. T_2 weighted images and MWF maps of control subject (columns A & B) and stenosis in a CSM patient (columns C & D). Slices shown correspond to C4 (rows 3 & 4) and C5 (rows 1 & 2). MWF maps are shown on a larger scale than T_2 weighted images. Colour bar indicates scale for MWF maps.

Table 1. Mean MWF in the dorsal column in healthy adults, CSM subjects, and control subjects, across all slices.

	N	Mean MWF	Mean S.D. b/w Slices
Healthy Adults	9	0.327 (0.006)	0.029 (0.004)
CSM Subjects	5	0.274 (0.009)	0.043 (0.007)
Significance b/w Groups		p = 0.010	p = 0.088
Control Subjects	1	0.317	0.072

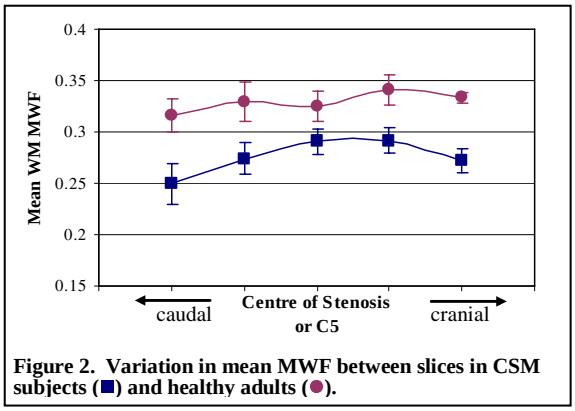

Figure 2. Variation in mean MWF between slices in CSM subjects (■) and healthy adults (●).

Conclusions

This study presents the first MWF calculated for human spinal cord white matter isolated from grey matter *in vivo*. With improved image segmentation, we expect to distinguish MWF differences in the white matter of ventral and lateral columns, as well as in grey matter. In addition, we illustrate the promise of T_2 relaxation imaging as a tool to investigate pathological changes in spinal cord white matter with a successful application to cervical spondylotic myelopathy.

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