FULL PAPER

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In Vivo Waveguide Elastography: Effects of Neurodegeneration in Patients with Amyotrophic Lateral Sclerosis

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Purpose: Waveguide elastography (WGE) combines magnetic resonance elastography (MRE), diffusion tensor imaging (DTI), and anisotropic inversions for a determination of the elastic properties of white matter. Previously, the method evaluated the anisotropic elastic properties of the corticospinal tracts (CSTs) of healthy volunteers. Here, the sensitivity of WGE is tested for the detection of pathologic changes in a cohort of patients with Amyotrophic Lateral Sclerosis (ALS).

Methods: MRE and DTI were performed in 14 patients with ALS and 14 healthy, age-matched controls. A comparison was made between three components from WGE and the DTI metrics FA, MD, PD, and RD, for the detection of differences between patients and controls. It was hypothesized that the stiffness values in the CSTs of the patients would be significantly lower due to the known neurodegeneration associated with ALS.

Results: Two anisotropic shear moduli polarized parallel and perpendicular to the CSTs were significantly reduced in ALS patients ($P < 0.0001$), whereas the anisotropic longitudinal modulus polarized parallel to the CSTs showed no significant differences.

Conclusion: The results of this study suggest a relatively high sensitivity of two anisotropic shear moduli as noninvasive metrics for the assessment of neuronal degeneration within the CSTs. **Magn Reson Med 000:000–000, 2013. © 2013 Wiley Periodicals, Inc.**

Key words: amyotrophic lateral sclerosis; magnetic resonance elastography; diffusion tensor imaging; anisotropic inversions; white matter tracts; waveguide elastography

INTRODUCTION

The development of improved methods for the noninvasive diagnosis of various conditions affecting the human brain is a very active area of research. In this context, both diffusion tensor imaging (DTI) (1) and magnetic resonance elastography (MRE) (2,3) have become increasingly important measurement methodologies. While DTI is capable of providing information pertaining to structural connectivity, diffusivity, and integrity of normal and diseased white matter (4–6), MRE enables the evaluation of the mechanical properties of the brain that is based on viscoelastic constants (7).

Thus far, MRE of the brain (8–11) has been applied to study global changes in cerebral viscoelasticity induced by physiological aging (12), multiple sclerosis (13), hydrocephalus, (14,15), Alzheimer disease (16), and meningioma (17). All of these studies were based on the assumptions of local homogeneity and isotropy of the evaluated viscoelastic constants. Two recent noteworthy publications have addressed transverse isotropy: one uses a combination of DTI and MRE in a phantom study (18), and the other analyzes gray and white matter in ex vivo lamb brains (19).

Previously, we introduced waveguide elastography (WGE), which combines DTI, MRE, spatial-spectral filtering, a Helmholtz decomposition, and inversions for the assessment of the anisotropic elastic constants of neuronal fiber bundles in five healthy human volunteers (20). Specifically, we used DTI to evaluate the fiber pathways of the corticospinal tracts (CSTs), which were observed to act as waveguides for externally induced shear waves at a 50-Hz excitation frequency. Three-dimensional vector field MRE was performed at the same spatial resolution and voxel position achieved by DTI in order to track the propagation of waves traveling at specific angles to the fiber directions. Using this waveguide methodology, we were able to analyze the viscoelastic properties of the CSTs using an orthotropic material model comprised of nine independent elastic constants. Redundancies in the solutions for the orthotropic coefficients indicated that the CSTs could be well represented by hexagonal anisotropy (transverse isotropy) comprised of five independent elastic constants.

In the current work, we tested the method regarding sensitivity to pathologic changes. Specifically, we investigated the stiffness of the CSTs in patients suffering from amyotrophic lateral sclerosis (ALS) and extended our approach by using two frequencies (50 and 60 Hz) in an attempt to evaluate the dependence of inversion performance on excitation frequency. ALS is a rapidly

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