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Quantitative Analysis of White Matter on DTI Images of Patients with Tinnitus: Preliminary Report

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Abstract— **Tinnitus is defined as an unwanted auditory perception of internal origin, usually localized, and rarely heard by others. Persisting appearances of tinnitus are most commonly combined with diseases or damage in the inner ear or neuro-auditory pathway. Diffusion tensor magnetic resonance imaging (DTI) is a new imaging method with the capability of providing non-invasive information on tissue microstructure not available in routine clinical MRI images. Since white matter regions of the brain are an ordered structure due to the myelination and directionality of axons and have a high degree of anisotropy, the ability to detect changes in anisotropy can be extremely useful in the study of diseases such as tinnitus and multiple sclerosis, which are assumed to involve the demyelination of axons. While several studies investigated tinnitus using MRI, few studies tried to analyze neurological disorders quantitatively using DTI. In this study, the cerebral volume of white matter on DTI images of patients with tinnitus was measured using the semi-automated and intuitive menu based image processing tool (Human Analyzer, ETRI, Korea). Total number of ten patients with tinnitus including three women was examined.**

I. INTRODUCTION

Tinnitus is defined as an unwanted auditory perception of internal origin, usually localized, and rarely heard by others. Tinnitus is a sensibly experienced ringing sensation in the auditory system, which occurs without the presence of an actual auditory stimulation. Tinnitus is a common disorder with many possible causes [1]. In several studies, it is suggested that the cause of tinnitus may be widely distributed within the auditory system. However, based on clear differences in the nature of awareness of tinnitus accomplished by many patients, tinnitus appearances can be categorized into two groups: peripheral tinnitus and central tinnitus. Peripheral tinnitus is considered to come from the peripheral nervous system and cochlea, while central tinnitus is considered to originate in the auditory cortex. Temporary existence of tinnitus may be experienced from sudden acoustic, mechanical or barometric trauma. Persisting appearances of tinnitus are most commonly combined with diseases or damage in the inner ear or neuro-auditory pathway [2].

Diffusion tensor magnetic resonance imaging (DTI) is a new imaging method with the capability of providing non-invasive information on tissue microstructure not available in routine clinical MRI images [3], [4]. This includes information regarding the degree of anisotropy as well as the direction of the diffusion of water molecules. Since white matter regions of the brain are an ordered structure due to the myelination and directionality of axons and have a high degree of anisotropy, the ability to detect changes in anisotropy can be extremely useful in the study of diseases such as tinnitus and multiple sclerosis, which are assumed to involve the demyelination of axons [5]-[7]. In particular, it is known that DTI is very effective to diagnose retrograde cerebral disorder such as dementia which is very difficult to be classified [8]. While several studies investigated tinnitus using MRI [9], [10], few studies tried to analyze neurological disorders quantitatively using DTI [11], [12]. In this study, white matter volume of tinnitus patients on DTI images was measured.

II. METHODS

A. Diffusion Tensor Imaging

All subjects were imaged on a 3.0 T clinical whole body magnet (VHi; GE Medical, USA). Diffusion tensor imaging was performed with the use of a single-shot spin-echo, echo-planar imaging technique, with Stejskal-Tanner diffusion-sensitizing pulses. The DTI imaging parameters were as follows: 220 x 220 mm^2 field of view (FOV), 128 x 128 matrix size, 16 to 19 axial slices, 5 mm slice thickness, TR (repetition time) = 8000 ms, TE (echo time) = 71 ms. Diffusion was measured along 24 non-collinear directions. For each slice and each gradient direction, two images with no diffusion weighting (b = 0 s/mm2) and diffusion weighting (b = 1000 s/mm2) were acquired. For anatomical MR images, a fast spin-echo (FSE) T2-weighted images were collected using following parameters; 220 x 220 mm^2 FOV, 128 x 128 matrix size, 16 to 19 axial slices, 5 mm slice thickness, TR = 8000 ms, TE = 71 ms. The slice locations were identical to the DTI measurement.

B. Diffusion Tensor Analysis

The diffusion in tissue can be mathematically represented as a symmetrical second-order cartesian tensor and the

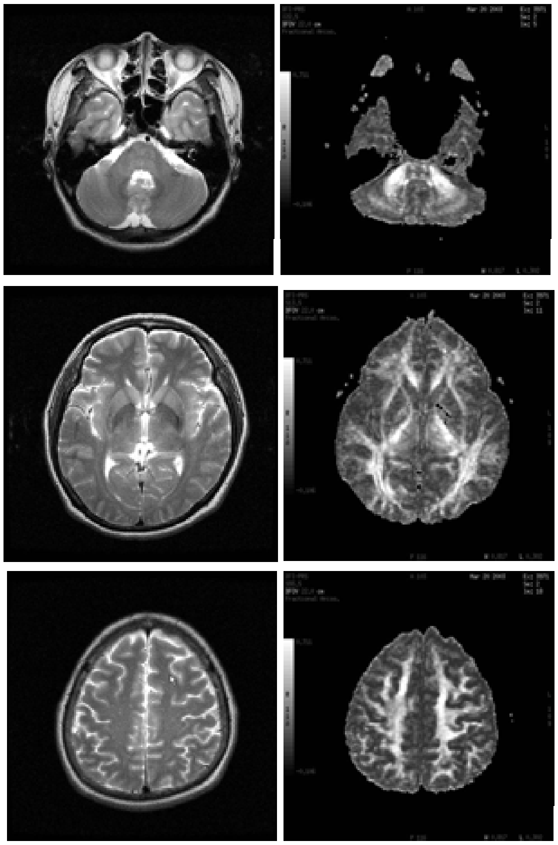

Fig. 1. Anatomical T2-weighted images (left) and corresponding DTI images (right) for different positions in the head of a patient with tinnitus.

diffusion tensor can be diagonalized using a similarity transform. The diagonal elements (D_1, D_2, and D_3) are the characteristic diffusion coefficients. Characteristic diffusion coefficients D_1, D_2 and D_3 are also mathematically known as eigenvalues. The largest, intermediate, and the smallest eigenvalues are referred to as the first, second, and third eigenvalues, respectively. For a second rank symmetric tensor, there are totally three rotationally invariant parameters (or three degrees of freedom). The choice of these invariants is not unique. For example, the three eigenvalues D_1, D_2 and D_3 can serve as a set of invariants. A tissue is considered to be fully isotropic when its anisotropy is equal to zero, and fully anisotropic when its anisotropy is equal to one. The average or apparent ADC (D_{avg}) corresponds to the average radii (r_{avg}) of the diffusion ellipsoid and the surface ADC (D_{surf}) corresponds to the surface area of the diffusion ellipsoid.

The diffusion tensor, which is obtained using DTI measurement, was then diagonalized, yielding eigenvalues D_1, D_2, D_3 as well as eigenvectors that define the predominant diffusion orientations. Based on the eigenvalues from the tensor, fractional anisotropy was calculated on a voxel-by-voxel basis and displayed as fractional anisotropy map. In addition, using eigenvectors, the orientation of

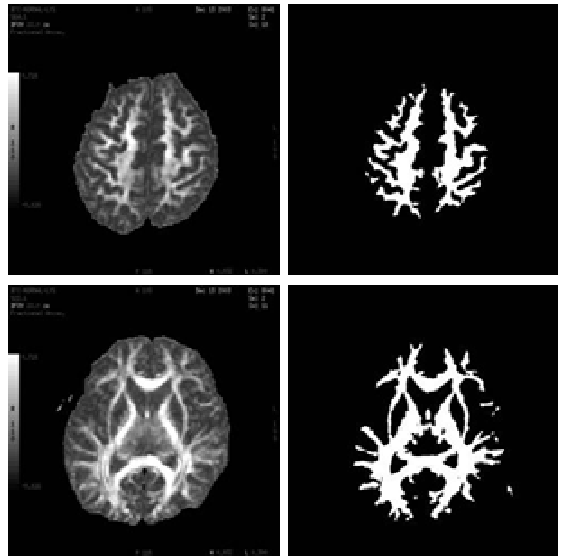

Fig. 2. DTI images (left) and corresponding segmented images (right) for different positions in the head of a tinnitus patient.

diffusion on each voxel was displayed as a colored orientation map. All tensor analysis and image processing were carried out on independent workstation (Advantage Window, GE Medical, USA). Finally, the fractional anisotropy values at auditory radiation were measured using a region of interest (ROI) analysis.

C. *Volume Measurements*

Total number of ten patients with tinnitus including three women was examined. The age was from 27 to 57 years. Volume of white matter was measured using the semi-automated and intuitive menu based image processing tool (Human Analyzer) [13]. White matter for each patient was segmented using the Human Analyzer and then the segmented results were counted in order to measure the cerebral volume of white matter for the patients with tinnitus.

III. Results

In Fig. 1, it is shown that anatomical MR images and DTI images for different slices in the head. Since DTI images show information regarding the degree of anisotropy as well as the direction of the diffusion of water molecules within the tissues, DTI images differ from the anatomical images.

It is shown that segmentation results of the DTI images for different slice in Fig. 2. The voxels in segmented region of white matter were counted in each slice and then total sum of the voxel number was obtained to calculate the white matter volume. The average volume of white matter was 913.3 ± 158.9 cm^3 for ten patients with tinnitus.

IV. Discussion

DTI is a new imaging method with the ability to provide non-invasive information on tissue microstructure not available in routine clinical MRI images. This includes information regarding the degree of anisotropy as well as the direction of the diffusion of water molecules. Since white matter regions of the brain are an ordered structure due to the myelination and directionality of axons and have a high degree of anisotropy, the ability to detect changes in anisotropy and volume can be extremely useful in the study of diseases such as tinnitus. For the first time as far as the authors know, it is presented quantitative analysis of the white matter volume of tinnitus patients on DTI images. Although data of ten patients were applied for this study, it is necessary to obtain sufficient number of patient data in order to analyze cerebral volume changes in tinnitus precisely. In the following study, the cerebral volume of white matter for normal subjects will be examined. This can help to investigate cerebral volume changes in tinnitus for diagnostic purposes.

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