Characterization of auditory, olfactory and sensory pathway functions by anisotropic diffusion using nuclear magnetic resonance imaging

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Abstract. One of the Nuclear Magnetic Resonance Imaging techniques is diffusion tensor imaging (DTI), which measures the rate of diffusion of extracellular water molecules found in tissues. The molecular diffusion can be obtained in the form of maps of the diffusion coefficients of the water in the tissues, as well as the brain in a non-invasive way with the Nuclear Magnetic Resonance (NMR). By using one of the advanced techniques magnetic resonance imaging (MRI), such as Diffusion Tensor Imaging (DTI) it is possible to obtain three-dimensional images of the neural connections of the white matter in the human brain; giving rise to new applications for neuroscience and to identify different brain disorders, such as degenerative diseases, schizophrenia, autism, etc. The diffusion by magnetic resonance image has been proposed as an approximation to obtain images of brain functions.

INTRODUCTION

Diffusion is a mass transport process that originates in nature, resulting from molecular mixing or particles without requiring mass movement. The diffusion should not be confused with the convection or dispersion of other transport mechanisms that require a massive movement to transport particles from one place to another. Within cerebral white matter, water molecules tend to diffuse more freely along the direction of axonal fascicles than across them. Such directional dependence of diffusivity is termed anisotropy\textsuperscript{1}. The two main parameters derived from DTI data are apparent diffusion coefficient (ADC) and fractional anisotropy (FA), FA reflects the directionality of molecular displacement by diffusion and vary between "0" (isotropic diffusion) and "1" (infinite anisotropic diffusion), ADC reflects the average magnitude of molecular displacement by diffusion. The more the ADC value, the more isotropic is the medium. DTI tractography allows virtual dissections of functional white matter tracts in the human brain in vivo using regions of interest (ROI)\textsuperscript{2}. The intricate trajectories of these pathways that can be identified using diffusion weighted MRI provide an important anatomical reference for evaluation of clinical disorders\textsuperscript{3} commonly associated in auditory\textsuperscript{4}, olfactory\textsuperscript{5} and sensory\textsuperscript{6} systems in pediatric brain.

MATERIALS AND METHODS

MR Imaging. 18 healthy children (ages 4-16 yrs) were examined, 6 girls and 12 boys with a middle age of 10 years. Imaging was performed in a 1.5T Philips scanner, head birndage coil with SENSE technology and 8 channels were used for fast imaging with a sequence of Fast Echo Planar Diffusion Weighted Imaging covering the whole brain, TR = 7711s, Echo train length 63, 90 flip angle, acquisition matrix 124x124, 15 directions of noncollinear gradients with fat suppression, 2mm gap.

Image Analysis. The diffusion tensor (DTI) was analized using MedINRIA (https://med.inria.fr/). Diffusion tensors were calculated pre- and post- motion correction to obtain generalized FA and ADC values. Segmentation of the different regions was manually drawn on midline sagittal 3D-T1 images. The study was approved by the Ethical...
Review Board. The functional pathways were segmented according to the literature.

**Auditory Pathway.** ROIs in this system were manually selected on the regions associated with the auditory system such as Heschl’s gyrus, the superior temporal gyrus and the auditory radiations. In order to obtain the complete tracts of the auditory system, to get the generalized diffusion parameters, that is, the values obtained from the complete auditory system.

**FIGURE 1:** Auditory pathway. a) Posterior view, b) left view, c) anterior view and d) right view

**Olfactory Pathway.** ROIs in this pathway were manually selected on regions of the brain associated with the olfactory system such as the olfactory bulbs, the olfactory cortex. Once the olfactory pathway was obtained, the diffusion values were measured.

**FIGURE 2:** Olfactory pathway. a) Posterior view, b) left view, c) anterior view and d) right view

**Sensory Pathway.** ROIs in this pathway were manually selected on regions of the brain associated with the sensory system such as the spinal lemniscus and medial lemniscus. Once the sensory pathway was obtained, the diffusion values were measured.

**FIGURE 3:** Sensory pathway. a) Posterior view, b) left view, c) anterior view and d) right view

The pathway obtained for each system were evaluated and approved by the team of neurologists of the Children’s Hospital of México Federico Gómez.
RESULTS

Fractional Anisotropy. The values of generalized FA obtained with their respective variance are, auditory system (0.338 ± 4.1 x 10^{-2}; 0.4546 ± 4.1 x 10^{-2}) (a.u.), olfactory system (0.278 ± 6 x 10^{-3}; 0.476 ± 2.2 x 10^{-2})(a.u.) and sensory system (0.4566 ± 6 x 10^{-3}; 0.458 ± 5.8 x 10^{-3})(a.u.).

\[ \text{FIGURE 4: FA values obtained according to age and sex of the patients for each functional system. a) Auditory System; b) Olfactory System; c) Sensory System.} \]

Apparent Diffusion Coefficient. The values of ADC obtained with their respective variance are, auditory system (1.879 ± 5.5 x 10^{-1}; 2.506 ± 9.1 x 10^{-1}) 10^{-3} mm^2/s, olfactory system (1.718 ± 4 x 10^{-2}; 2.761 ± 0.014)10^{-3} mm^2/s and sensory system (1.72 ± 7.5 x 10^{-2}; 2.32 ± 1.6 x 10^{-2})10^{-3} mm^2/s.

\[ \text{FIGURE 5: ADC Values obtained according to age and sex of the patients for each functional system. a) Auditory System; b) Olfactory System; c) Sensory System.} \]

DISCUSSION AND CONCLUSIONS

The values of ADC are predominantly caused by the orientation of fiber tracts in white matter and is influenced by its micro and macro structural features, and a measure of the magnitude of diffusion (of water molecules) within tissue.

The figures show Generalized FA values (figure 4) and ADC values (figure 5) of the auditory system, olfactory system and sensory system respectively. It can be seen that the FA and ADC values change according to age and sex younger age. According to the brain development, myelination is different depending of the age, development of white matter, is useful in assessment of normal myelination development in the infantile brain.
For the auditory system, a decrease in ADC values and an increase in FA values can be seen as the brain develops. For the Olfactory System ADC values present an increase and decrease of such values as the tracts specialize, while the values of FA increase. For the Sensory System ADC values do not show large changes in the values for this diffusion parameter, meanwhile the values of FA increase.

The structural data observed are related to the classic neuroanatomical descriptions with the great advantage of having the ADC and AF measurement that allows to have quantitative measurements that can be used in comparative studies. FA, for example, already has evidence of its usefulness as a biomarker and has been shown to correlate with the presence of pathological changes. In the same way, tractography is a non-invasive technique that is already used as a tool that allows surgical planning in brain tumors.

The use of the DTI imaging technique with the ability to discern the orientation of white matter tissues and the ability to reconstruct its structure in 3D has opened the door to selective brain studies in the healthy and diseased human brain. Being able to extract several parameters of diffusion that allows to study the normal development of the brain and its specialization of tracts to obtain values of control of the parameters of diffusion and compare them with those of unhealthy patients, can be a tool that allows the detection of diseases such as glaucoma, epilepsy, multiple scleroses, etc. The applications of this technique lies in its use to analyze neurodevelopment, it has a lot of potential to be used to analyze demyelinating diseases and in others where there is destruction of the tracts (spinal muscular atrophy). The vast majority of literature is oriented to the study of adults, so there is not enough information to guarantee the detection of anomalies in the development of white matter in the human brain in early age. Research carried out in pediatric population could accelerate the clinical diagnosis of diseases or malformations in human brains.

ACKNOWLEDGMENTS

Hospital Infantil de México Federico Gómez and radiologist technicians Porfirio Ibáñez and Manuel Obregón

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