Age and Gender - Related Changes in the Normal Human Brain Using Hybrid Diffusion Imaging (HYDI) with Neurite Orientation Dispersion and Density Imaging (NODDI) Analysis

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Target Audience MRI scientists who focus on diffusion imaging of brain microstructures, Psychiatrists, Neuroscientists, Clinicians

Purpose Diffusion Tensor Imaging (DTI) is widely used to characterize water diffusion and microstructure in biological tissues, particularly in the brain[1]. DTI uses a simple, 3D, multivariate Gaussian model to describe the diffusion behavior of water molecules[2]. Recently, diffusion models including Composite Hindered and Restricted Model of Diffusion (CHARMED)[3], Neurite Orientation Dispersion and Density Imaging (NODDI)[4], and Diffusional Kurtosis Imaging (DKI)[5] with multiple diffusion compartments were proposed to better describe water diffusion behavior in biological tissues and hence yield more accurate and interpretable diffusion related quantities. In this abstract, NODDI model was used to study brain changes over the course of normal aging. A multiple-shell diffusion acquisition scheme, Hybrid Diffusion Imaging (HYDI)[6], was used in this study. HYDI with five concentric shells is suitable for different diffusion data processing strategies and helps to bridge clinical findings between the simple tensor model, complex diffusion models, and model-free approaches.

Methods HYDI data were acquired on 52 right-handed healthy volunteers (18-71 years old). Among them, 29 subjects were female. Scans were performed on a 3T GE-SIGNA scanner with an 8-channel head coil and ASSET parallel imaging. The Diffusion Weighted (DW) pulse sequence was an SS-SE-EPI sequence with pulse oximeter gating. TR was between 10-15 heart beats (12-15 s). The other MR parameters were: TE = 122 ms, δ/Δ=45/56 ms, voxel size=2x2mm^2, 40 slices with slice thickness=3mm, SENSE factor=2 and a total scan-time of about 24 min. NODDI was processed using all the shells of the HYDI data. The orientation dispersion index (odi) describing the dispersion of white matter (WM) fibers, the intracellular volume fraction (ficvf) and the volume fraction of the cerebral spinal fluid (CSF) compartment (fiso, data not shown) were generated using the NODDI model. For each subject, means of odi, ficvf and fiso were calculated on the whole-brain WM as well as on 3D ROIs at the splenium of the corpus callosum (CCs), the genu of the corpus callosum (CCg) of the corpus callosum, and the internal capsule (IC). Lastly, the means were linearly regressed against age for whole-brain WM and each ROI.

Results

Representative maps of odi, ficvf and fiso from an 18 years old male are shown in Figure 1. White matter in the odi map looks darker than grey matter indicating the coherent nature of WM fibers (Figure 1(i)). Intracellular volume fraction (ficvf) describing axonal density had higher signal in WM than gray matter (Figure 1(ii)). As expected, CSF had high intensity in the fiso map (Figure 1(iii)). Figure 2 shows the linear dependency of odi against age for whole-brain WM. Males had a significantly higher slope ($p < 0.05$) on whole-brain WM compared to females, indicating a faster change of white matter over age than females. The slope, β1, the correlation coefficient, R, the p-value from the linear regression of ficvf and odi against age for whole-brain WM, CCg, CCs and IC are summarized in Table 1. Male subjects showed a significant change of odi in whole brain WM and in IC whereas females showed such a behavior in CCg only. For the ficvf, only male subjects had a significant change in whole brain WM. The fiso did not show significant changes over age in all ROIs studied.

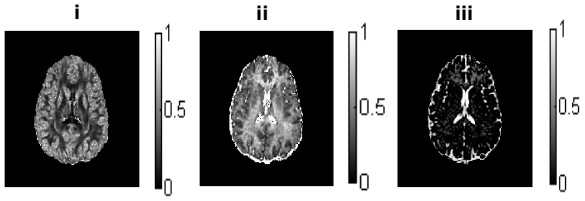

Figure 1: NODDI maps of an 18 years old male; i- odi, ii-ficvf and iii-fiso

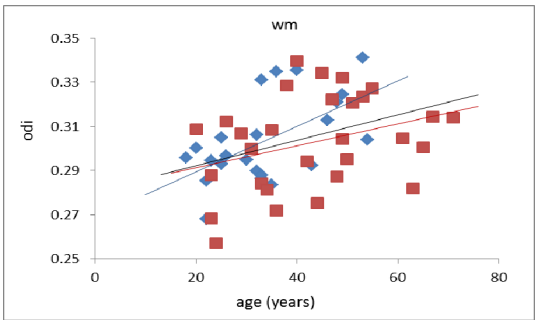

Figure 2: odi vs. age for whole-brain WM; blue diamonds – males, red squares –females. The black line is the fit for the all data.

Table1: *odi = β1*age + c. The numbers in blue indicate significant results (p < 0.05)*

ROI	statistics	odi			ficvf		
		Female	male	all	female	Male	all
WM	β_1	0.0006	0.001	0.0005	0.0002	0.0015	0.0004
	R	0.3296	0.5750	0.3822	0.0985	0.5129	0.1525
	p value	0.0808	0.0041	0.0052	0.6113	0.0123	0.2805
CCg	β_1	0.0007	0.0004	0.0005	-0.0009	0.0018	-0.0003
	R	0.4601	0.2427	0.3614	-0.2675	0.3424	-0.0705
	p value	0.0120	0.2645	0.0085	0.1606	0.1097	0.6193
CCs	β_1	-0.0002	0.0006	$2x10^{-5}$	0.0005	0.0005	$-4x10^{-6}$
	R	-0.1492	0.3820	0.0151	0.1052	0.1024	-0.0007
	p value	0.4400	0.0720	0.9151	0.5871	0.6418	0.9960
IC	β_1	0.0002	0.0007	0.0002	$2x10^{-5}$	0.001	$5x10^{-5}$
	R	0.2079	0.4868	0.2096	0.0098	0.2936	0.0321
	p value	0.2791	0.0185	0.1359	0.9598	0.1739	0.8212

Discussion The results suggested that the WM organization referred by odi seems to be more sensitive with normal aging whereas the overall intracellular volume fraction remains stable over the aging course, except in males. Among the significant findings, odi increased with aging, which is consistent with previous published DTI results of reduced FA over aging[7]. The male brain may be more susceptible to effects of aging than female. The genu of the corpus callosum showed more significant changes due to the aging effect while the splenium showed no significant findings.

Conclusion This study showed that the HYDI encoding scheme is versatile and the HYDI data may fit the NODDI model. Aging effect is more apparent in male brains. Further studies will include Enhanced CHARMED model and Kurtosis model for detail comparison. ..

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