Directional diffusion kurtosis analysis of rat brain maturation

M. M. Cheung[1,2], E. S. Hui[1,2], and E. X. Wu[1,2]

[1]Laboratory of Biomedical Imaging and Signal Processing, The University of Hong Kong, Pokfulam, Hong Kong, [2]Department of Electrical and Electronic Engineering, The University of Hong Kong, Pokfulam, Hong Kong

Introduction

The diffusion properties of developmental changes in rat brain were studied by Diffusion Kurtosis Imaging (DKI). There is modification of both white matter (WM) and gray matter (GM) during maturation of the brain [1]. In WM, these microstructural alterations include myelination, increase in fiber diameter and changes of the extracellular environment. DTI has been employed extensively to quantify these alterations. DKI is a recently developed technique which is capable of revealing non-Gaussian diffusion information in biological tissue [2,3]. The effect of these subtle developmental changes to the tissue complexity is measured by DKI in this experiment. The diffusion characteristics and the structural information provided are essential in better understanding of developmental and aging physiology.

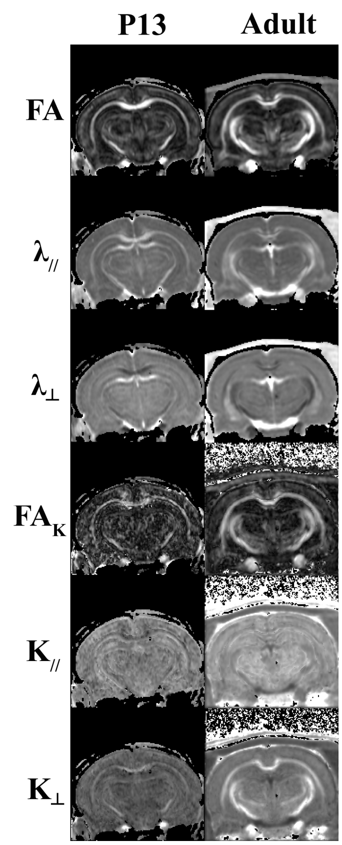

Figure 1. DTI and DKI derived maps of P13 and adult rat

Methods

Experiments were carried out on normal Sprague-Dawley rats at various stages, using a Bruker PharmaScan 7T scanner. The sample sizes were n=6 at postnatal 13 days (P13) and n=7 for adult rats. All diffusion weighted images were acquired with a respiration-gated spin echo 4-shot EPI sequence. A total of 5 b values (0.5, 1, 1.5, 2, 2.5 ms/μm^2) were applied with an encoding scheme of 30 gradient directions [4].The imaging parameters were: ***P13 rats***: TR/TE = 3000/33.3 ms, δ/Δ = 5/20 ms, slice thickness = 0.7 mm, FOV = 25 mm, data matrix=128x128 (zero filled to 256X256), NEX = 2. ***Adult rats***: TR/TE = 3000/36 ms, δ/Δ = 5/17 ms, slice thickness = 1 mm, FOV = 30 mm, data matrix = 128x128(zero filled to 256X256), NEX=4. The apparent diffusion coefficients (D_{app}) and apparent kurtoses (K_{app}) were obtained from $\ln[S(b)] = \ln[S(0)] - bD_{app} + (1/6)b^2 D_{app}^2 K_{app}$ [2,3]. Kurtoses along the eigenvectors of diffusion tensor (DT) were computed by transformation of diffusion kurtosis tensor to the coordinate system of the eigenvectors [5].$K_{//}$ is the kurtosis along the direction of principle eigenvector and $K_{\perp}$ was the average of the other two orthonormal directions. A newly proposed anisotropy of kurtosis, FA_K, is defined as $\sqrt{(3/2)\sum_{i=1}^{3}(K_i - MK)^2 \Big/ \sum_{i=1}^{3} K_i^2}$. Regions of interests (ROI) were manually drawn by referencing to a rat brain atlas. 4 dominant white matter (WM) structures include corpus collosum (CC), external capsule (EC), cerebral peduncle (CP), anterior commissure (AC) and 3 grey matter (GM) regions include cortex (CT), hippocampus (HP) and cauduate putamen (CPu) were defined.

Results and Discussions

The FA, $\lambda_{//}$, $\lambda_{\perp}$, FA_K, $K_{//}$, $K_{\perp}$ map of the two groups were shown in Fig. 1. The measurement and the comparison were made in Fig. 2. Directional diffusivities in some structures were significant different. However, the DKI derived parameters were found to be much more sensitive to the developmental changes of diffusion environment. Restriction in both $K_{//}$ and $K_{\perp}$ were much smaller in neonatal rats in all chosen structures. The increase in $K_{\perp}$ was found to be much higher than that of $K_{//}$, implying more restricted barrier formation in the radial direction. Apart from myelination, microstructural environment changes in axon should also be taken into account. The degree of anisotropy measured by FA_K was interesting. There is higher anisotropy in WM but that in GM drops in brain maturation. FA_K could be a more sensitive quantification of anisotropy and DKI is proved to provide independent information from DTI.

Conclusion

Directional kurtoses and FA_K were demonstrated to have high sensitivity in brain maturational process. The restriction in radial direction increases dramatically as age grows. Further investigation is required to apply this new tool in studying tissue complexity and time course of maturation of individual structures.

References

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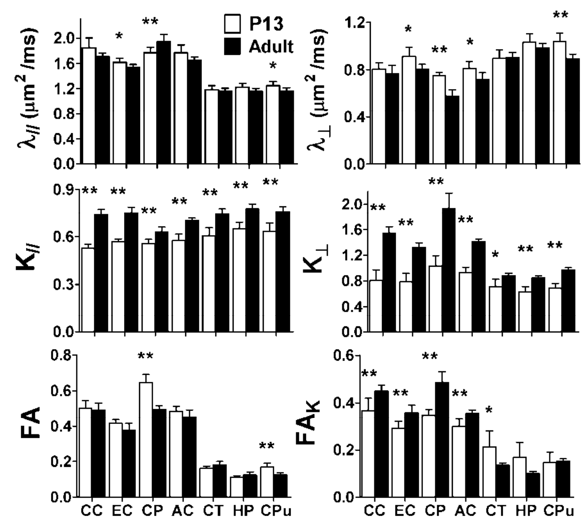

Figure 2. ROI measurements of different structures. (* p<0.05, ** p<0.01 indicates significant difference between the two groups in two-tail t-test)