The detection of microstructural changes in cerebral gray matter nuclei between healthy neonates and young adults by diffusional kurtosis imaging

Qinli Sun[1], Xianjun Li[1,2], Yanyan Li[1], Jie Gao[1], Huan Li[1], and Jian Yang[1,2]

[1]*Department of Diagnostic Radiology, The First Hospital of Medical School, Xi'an Jiaotong University, Xi'an, Shaanxi, China,* [2]*Department of Biomedical Engineering, School of Life Science and Technology, Xi'an Jiaotong University, Xi'an, Shaanxi, China*

Introduction

The in vivo detection of microstructural change in gray matter (GM) is curial important during human brain development. Diffusion tensor imaging (DTI) is not truly effective in characterizing the water diffusion changes in relatively isotropic GM and has the limitation to reveal the heterogeneity of biologic tissues[1~4]. Diffusion kurtosis imaging (DKI) is an extension of DTI and can reflect the non-Gaussian diffusion in tissues, allowing more comprehensive characterization of microstructural changes during brain development[3~6]. The purpose of this study is to compare the sensitivity between diffusion tensor and kurtosis metrics on detecting the changes of the cerebral gray matter nuclei between health neonates and young adults.

Methods

This study was approved by the local institutional review board and written informed consents were obtained from the adult subjects and the parents of the neonates subjects. Twenty-two health term neonates (11 males and 11 females; gestational age of 38~41weeks with median of 39 weeks; the postmenstrual age (PMA) of 39 ~ 44 weeks with median of 40 weeks) and twenty-two health young adults (11 males and 11 females; gestational age of 37~40 weeks with median of 39 weeks; age of 18~26 years with median of 22 years) underwent diffusional kurtosis imaging. A single short echo planar imaging sequence was performed for acquisition of DKI datasets by using an 8-channel phase array radio-frequency head coil in a 3.0T scanner (Signa HDxt, General Electric Medical System, Milwaukee, WI, USA). DKI was carried out with the following variables: b values = 0, 500, 1000, 2000 and 2500 s/mm2; 18 gradient directions per nonzero b value; NEX = 1; TR = 8000~11000ms; TE range=91.7~126.1ms; 22~33 slices with slice thickness = 4 mm, no gap; field of view = 180×180 mm^2 for neonates and 240×240 mm^2 for young adults; matrix = 128×128. Artifact-corrupted diffusion weighted images were excluded by using an automated method[7]. Diffusion tensor and kurtosis tensor were estimated by using constrained weighted linear least squares. Fractional anisotropy (FA), mean diffusivity (MD), radial diffusivity (RD), axial diffusivity (AD), Mean kurtosis (MK), axial kurtosis (AK) and radial kurtosis (RK) were calculated by using the DKI model. Four regions of interest (ROIs) of the cerebral gray matter nuclei were selected based on the atlas (as shown in **Fig. 1a**) including thalamus, putamen, globus pallidus and caudate nucleus. Inter-group differences of the regional values were tested by using the Mann-Whitney Test on SPSS version 13.0 (SPSS Inc., Chicago, IL, USA). The relative change ratios of parameters = (mean values of adults – mean values of neonates) / mean values of neonates.

Results

The representative maps for FA, MD, AD, RD, MK, AK and RK of the neonate and adult subjects were shown in **Fig. 1b**. The regional values in ROIs were shown in **Fig. 1c.** There were significant differences for all seven parameters between neonates and adults in four GM regions ($p<0.05$), except AD in thalamus($p=0.944$). The relative change ratios of MK(139.39%, 157.14%, 179.41%, 91.18% respectively in thalamus, putamen, globus pallidus and caudate nucleus), AK (106.06%, 151.72%, 155.88%, 82.86%) and RK (172.73%, 165.52%, 210.81%, 91.14%) were larger than those of FA (55.56%, 37.5%, 70.59%, 30.77%), MD (-4.58%, -27.73%, -19.83%, -16.56%), AD (3.25%, -1.45%, -10.22%, -15.05%) and RD (-9.17%, -30.28%, -25.71%, -17.88%).

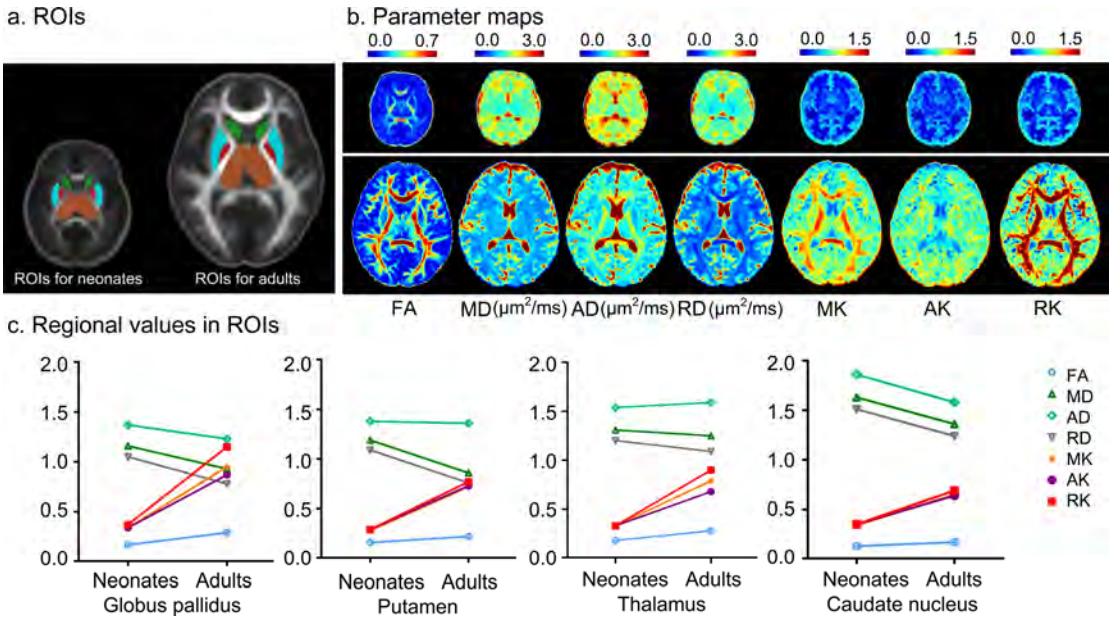

Fig.1 (a)ROIs overlap on the mean FA; (b) FA, MD, AD, RD, MK, AK and RK maps of the representative neonate and adult subjects. (c) The mean values of FA, MD, AD, RD, MK, AK and RK in ROIs compare between neonates and young adults.

Discussion

In this study, we compared the changes of DKI parameters in four gray matter nuclei between health neonates and young adults. Compared to neonates, FA, MK, AK and RK increased while MD, AD and RD reduced in young adults. The relative change of the kurtosis metrics varied from 82.86% to 210.81% while that of diffusion tensor metrics just from 1.45% to 70.59%. The kurtosis metrics had bigger variations than those in the diffusion tensor metrics. GM maturation processes include the addition of basal dendrites, modification in tissue water content, proliferation of cell membranes and organelles, cell packing density and changes in cortical cytoarchitecture[1~2,4]. Take into account the non-Gaussian diffusional properties of water motion in complex media, DKI possess the more sensibility and comprehensive for evaluating gray matter microstructural complexity[4~6].

Conclusion

DKI offers a more comprehensive and sensitive characters for detection of microstructural changes by measuring directionally specific diffusivity and kurtosis, and has the potential to explore the development process of gray matter.

Acknowledgement This study was supported by grant from National Natural Science Foundation of China (No.81471631,81171317 to JY).

References

1. Mukherjee P, Miller JH, Shimony JS, et al. Diffusion-tensor MR imaging of gray and white matter development during normal human brain maturation. AJNR Am J Neuroradiol 2002;23;1445–56. **2.** Huˮppi PS, Dubois J. Diffusion tensor imaging of brain development. Semin Fetal Neonatal Med 2006;11:489 –97. **3.** Jensen JH, Helpern JA. MRI quantification of non-Gaussian water diffusion by kurtosis analysis. NMR Biomed 2010;23:698 –710. **4.** Cheung MM, Hui ES, Chan KC, et al. Does diffusion kurtosis imaging lead to better neural tissue characterization? A rodent brain maturation study. Neuroimage 2009;45: 386–92. **5.** Yoshida S, Oishi K, Faria AV, et al. Diffusion tensor imaging of normal brain development. Pediatr Radiol 2013; 43:15–27. **6.** Paydar A, Fieremans E, Nwankwo JI, et al. Diffusional Kurtosis Imaging of the Developing Brain. AJNR Am J Neuroradiol 2014 Apr; 35(4):808-14. **7.** Li X, Yang J, Gao J, Luo X, et al. A robust post-processing workflow for datasets with motion artifacts in diffusion kurtosis imaging. PLoS One. 2014 Apr 11;9(4):e94592.