Effect of Cerebral Hemodynamic Changes on DTI Quantitation: A Hypercapnia Study

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Introduction

Quantitative diffusion tensor imaging (DTI) is now widely used to probe the microstructural changes in neural tissues [1,2], where its absolute quantitation accuracy and reproducibility become essential. However, quantitation of DTI indices in vivo can be confounded by the presence of cerebral vasculature and blood perfusion [3]. This study aims to quantitatively examine the effect of cerebral hemodynamic changes on DTI indices by using a hypercapnia model.

Methods

Hypercapnia Paradigms: 6 female adult Sprague-Dawley rats were anesthetized using isoflurane (3% induction and 1.5-2% maintenance) via a nose cone. 48 continuous DTI acquisitions including 6 pairs of normocapnia (OFF)/hypercapnia (ON) were performed. Each pair included 5 DTI acquisitions for normocapnia (OFF) with room air inhalation and 3 DTI acquisitions for hypercapnia (ON) with 5% CO_2/air inhalation delivered into the nose cone [4]. Respiration rate, heart rate, arterial oxygen saturation and rectal temperature were monitored throughout the experiments.

MRI Protocols: All MRI measurements were acquired using a 7T Bruker scanner. In vivo Diffusion-weighted (DW) images were acquired with a SE 2-shot EPI sequence with 6 diffusion gradient directions. Five additional images with b-value=0 (B_0 images) were also acquired, yielding a scan time of 85 seconds per DTI acquisition. The imaging parameters were: TR/TE=2500/31ms, δ/Δ=5/17ms, FOV=4.5x4.5cm^2, acq matrix= 96x96 (zero-filled to 256×256), slice thickness =1mm (0.2mm gap), b-value of 1000 and 300s/mm^2.

Data Analysis: RAW data were first co-registered within individual animal using AIR5.2.5. FA, mean diffusivity, axial and radial diffusivities were calculated from DWIs with two b-values, 0 versus 1000 or 300 s/mm^2 respectively. Whole brain area in each animal was first defined based on the mean of 48 FA maps, and then the brain was segmented based on FA and MD into gray matter (GM, MD<1.6 ms^2/ms, 0.03<FA<0.31), white matter (WM, MD<1.6 ms^2/ms, FA>0.31) and CSF (MD>1.6 ms^2/ms). These regional masks were used to quantify the regional changes of various DTI indices.

Results

Fig.1 shows the average physiologic recordings in all acquisition sessions. Representative GM, WM regional masks are illustrated in Fig.2. Fig.3 shows that the MD histogram shifted to higher diffusivity during hypercapnia. Fig. 4 illustrates the average MD time courses computed with b value of 1000 and 300s/mm^2 in all animals. For whole brain, the peak-to-peak percentage increases were measured as 1.56±0.49% and 3.21±0.72% for b=1000 and 300s/mm^2, respectively. Regionally, MD increases were found to 1.58±0.49% in GM and 1.69±0.58% in WM (Fig.5). In addition, FA was observed to generally decrease during hypercapnia in both GM and WM (Fig. 6).

Discussions and Conclusions

Our data showed both MD, axial and radial diffusivities change globally and regionally to respond to hypercapnia, suggesting that vasculature alterations can affect *in vivo* DTI quantitation. The effect of hemodynamic alterations on DTI was more pronounced at lower b because of increased pseudo diffusion effect of blood perfusion. In this study, FA was found to decrease during hypercapnia likely because of the more pronounced pseudo diffusion effect that was associated with relatively random capillary vasculature. These findings indicated that alterations in physiologic conditions, vascular characteristics and hemodynamic regulations can affect the absolute quantitation of various DTI indices in vivo. Therefore, caution must be taken in designing experiments and interpreting DTI indices.

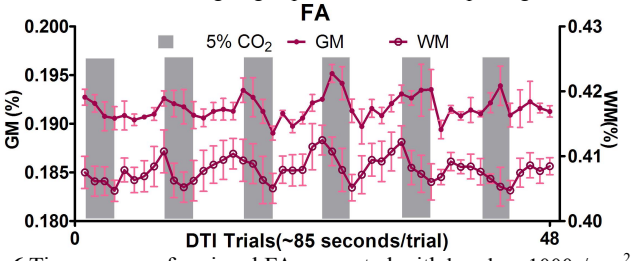

Fig.6 Time course of regional FA computed with b-value=1000s/mm^2.

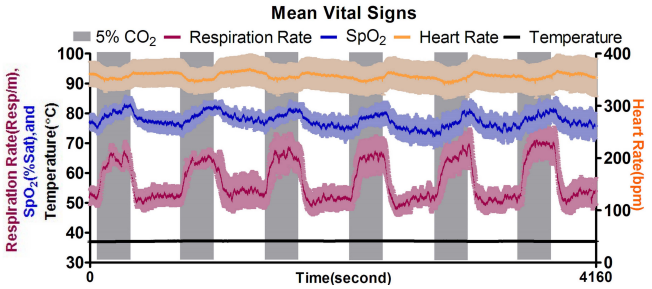

Fig.1 Continuous vital signs recorded throughout 48 DTI acquisitions were shown in mean and SD.

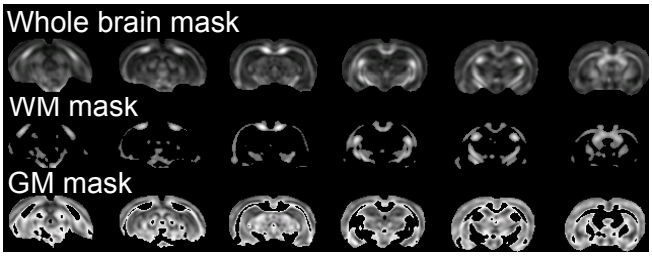

Fig.2 Whole brain, white matter and gray matter masks were overlaid on the mean FA map of a representative animal.

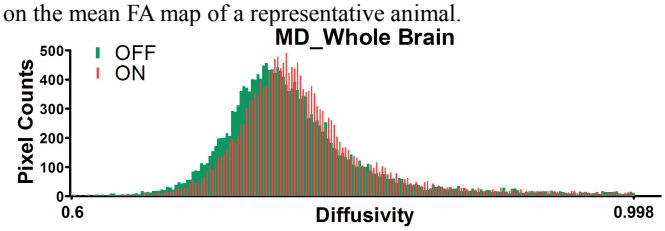

Fig.3 Typical histograms of whole brain mean diffusivity during hypercapnia (ON) and normocapnia (OFF).

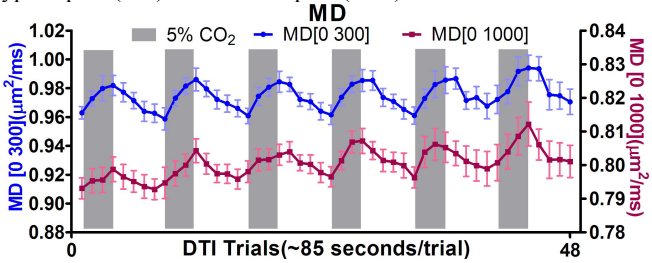

Fig.4 Time course of whole brain MD quantitation computed with b-value of 1000 and 300s/mm^2.

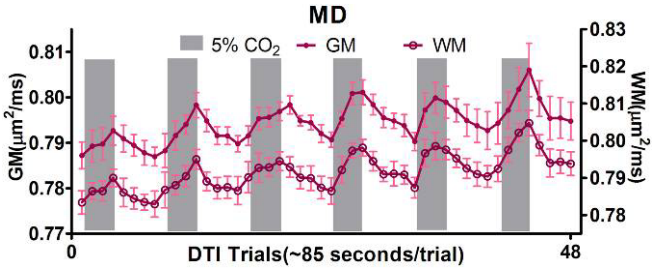

Fig.5 Time course of regional MD computed with b-value=1000s/mm^2

References

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