Case report

DIFFUSION MRI IN THE POSTMORTEM BRAIN: CASE REPORT

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SUMMARY
Postmortem brain of a ten-month-old child was examined by MR imaging, and diffusion MR imaging at the 12th hour after death in order to disclose the cause of death. There were basal ganglion lesions indicating a mitochondrial disorder. There was a prominent difference between the ADC values of the white matter \((0.28 \pm 0.04 \times 10^{-3} \text{mm}^2/\text{s})\) and cortex \((0.42 \pm 0.04 \times 10^{-3} \text{mm}^2/\text{s})\), and this was statistically significant \((p<0.0001)\). This difference suggested that in the postmortem brain the conditions in the white matter leading to restriction of movement of water molecules are more severe than that in the cortex.

Key words: postmortem, diffusion-weighted, MRI, ADC map, brain.

INTRODUCTION
A number of studies dealt with MR imaging (MRI) in the diagnosis of brain death, and there are a few diffusion MRI papers reporting the findings in the postmortem brain \([4, 5, 6, 7]\). In this paper, a postmortem case is presented examined by MRI and diffusion MRI at the 12th hour after death. A detailed description of diffusion MRI findings mainly those on apparent diffusion coefficient (ADC) maps are reported herein.

CASE REPORT
A ten-month-old girl was admitted to the emergency department because of prominent vomiting. Neurologic evaluation revealed developmental delay, and severe hypotonia. Increased lactate levels were noted in the serum. She was treated with intravenous administration of sodium bicarbonate, however, she died a few hours after admission. Brain death was evidenced by a flat EEG read at maximum gain, no cranial reflexes, no respiration, and no response to noxious stimuli. Autopsy was not permitted, and the clinicians requested a postmortem brain MRI study for etiological diagnosis purposes. An MRI study including diffusion MRI was performed 12 hours after death.

The MRI examination was performed on a 1.5 T MR unit, Magnetom Vision, Siemens (Erlangen, Germany) with a maximum gradient strength of 30mT/meter, and a rise time of 600 microseconds. T1 and T2-weighted sequences were acquired, and a spin-echo, echo-planar diffusion MRI sequence (using three gradient directions) was added to the imaging protocol with TR=4000 msec, and TE=110msec, acquired in 32 sec (FOV=230, matrix=96×128, pixel size=2.40×1.80). \(b=1000 \text{mm}^2/\text{s}\) (heavily diffusion-weighted) images, and apparent diffusion coefficient (ADC) maps were studied. ADC maps were automatically generated by the sequence for each slice, and ADC values were obtained by direct readings of ROI and pixel lens evaluations from the maps with multiplying the obtained values with the constant "\(\times 10^{-3}\) mm\(^2/\text{s}\)."

In the postmortem brain, a reduction of gray-white matter differentiation was evident on T1 and T2-weighted images. There were prominent changes in the caudate nuclei, and putamina. The center parts of these were hyperintense on T1-weighted images, and hypointense on T2-weighted images, consistent with presence of hemorrhagic products. Their rims were hypointense on T1-weighted images, and hyperintense on T2-weighted images (figure 1a). There was a prominent signal difference in the pons, anterior part being hypointense and posterior part hyperintense. The MRI changes, in association with clinical findings, suggested a diagnosis of a mitochondrial disorder.

With respect to diffusion MRI, on \(b=1000\text{mm}^2/\text{s}\) (heavily diffusion-weighted) images the basal ganglion lesions were hypointense compared to the surroundings. The white matter was hyperintense to the cortex. ADC maps provided apparently detailed view than...
these as well as numeric measurements of diffusion coefficients (figure 1b, 1c and 1d). ADC maps revealed clear differentiation of the cortex and white matter, and the former appeared to be swollen compared to the latter (figure 1c). Multiple measurements of the ADC values in the postmortem brain parenchyma (cortex and white matter) ranged between 0.16 to 0.48 $\times 10^{-3}$ mm$^2$/s (mean=0.34±0.05). However, the mean ADC value in the white matter (0.28±0.04 $\times 10^{-3}$ mm$^2$/s) was prominently lower than that of gray matter.

**FIG. 1.** – a) T2-weighted image reveals changes in the caudate nuclei, and putamina with hypointense centers and hyperintense rims. Hemorrhagic products are likely present in the cores. Reduction of gray-white matter differentiation is evident throughout the brain. b) ADC map. ADC values were read by pixel lens evaluations (each covers 16 pixels). The rim of the right putaminal lesion has a value of 1.23 $\times 10^{-3}$ mm$^2$/s, and the core of the left putaminal lesion has a value of 0.63 $\times 10^{-3}$ mm$^2$/s. ADC values from mesencephalon (0.18 and 0.28), right frontal cortex (0.42), and right temporal cortex (0.45) are shown. c) ADC map. The cortex appears to be swollen compared to the white matter. Two ADC measurements are shown by ROI evaluations; that from white matter is 0.21 $\times 10^{-3}$ mm$^2$/s, and the other from the cortex is 0.46 $\times 10^{-3}$ mm$^2$/s. This suggests that the tissue of the cortex is looser than that of the white matter. d) ADC map. Map covers cerebellum, pons, temporal, and frontal lobes. A value from the right frontal region is 0.41 $\times 10^{-3}$ mm$^2$/s, from the cerebellum is 0.47 $\times 10^{-3}$ mm$^2$/s, from the pons is 0.28 $\times 10^{-3}$ mm$^2$/s, and from the right hippocampal region is 0.34 $\times 10^{-3}$ mm$^2$/s.
(0.42±0.04 ×10⁻³ mm²/s), when the values were calculated separately (figure 1c). This was statistically significant by Wilcoxon test for paired data (p<0.0001). With respect to the basal ganglia lesions the center parts revealed values ranging from 0.61 to 0.66 ×10⁻³ mm²/s, while the rims had values ranging from 1.16 to 1.43 ×10⁻³ mm²/s (figure 1b). Low ADC values from other regions of the brain are shown in 1d.

**DISCUSSION**

Diffusion MRI is a relatively new sequence in clinoradiologic applications, mainly reflecting molecular motion of water within the tissue, thus providing data on tissue integrity. Its main clinoradiologic applications have included studies on ischemia/infarction, and distinction of cytotoxic edema from vasogenic edema, and a number of other conditions. Especially, automatically generated ADC maps in the diffusion imaging sequence are free from T2 shine through effects, and they provide significant quantitative information regarding tissue integrity in the brain [2, 3, 8, 9, 10].

A number of recent diffusion MRI studies have provided normal ADC values of the cerebral white matter. It appears that there is a consensus that the mean ADC value of the normal white matter is about 0.80 ×10⁻³ mm²/s, ranging approximately between 0.60 and 1.05 ×10⁻³ mm²/s [2, 3, 8, 9, 10]. A study reported that the values for acute infarction approximately range between 0.16 and 0.58×10⁻³ mm²/s with a mean value of 0.34±0.11 ×10⁻³ mm²/s [9]. The overall low mean ADC value in the post-mortem brain (0.34±0.05 ×10⁻³ mm²/s) 12 hours after death was identical to that in acute cerebral infarction mentioned above. Similarly, Lovblad et al. [6] have reported dropped ADC values in brain death. Also, Nakahara et al. [7] studied four deeply comatose patients with severe brain injury. One of their patients was diagnosed as clinically brain dead, and the patient’s ADC values of gray and white matter were significantly lower than those of three other brain-injured patients. In addition the ADC value of white matter was significantly lower than that of gray matter [7]. On the other hand, it is known that in patients with acute infarction in a vascular territory, the white matter and cortex are involved in a similar manner. Of particular note, however, in the postmortem brain herein the cortex appeared to be swollen compared to the white matter, and the mean ADC value in the white matter (0.28±0.04 ×10⁻³ mm²/s) was prominently lower than that in the cortex (0.42±0.04 ×10⁻³ mm²/s), which was statistically significant (p<0.0001). This difference suggests that at postmortem 12 hours the conditions in the white matter leading to restriction of movement of water molecules are more severe than that of the cortex, and the swollen cortical tissue is looser with relatively more mobility of water molecules. In a recent experiment by Branco [1] it was shown that transition of water from the sol to the gel state, can contribute to the signal on diffusion MRI, and in gel state high signal is observed on b=1000s/mm² images (this should result in low signal and low ADC values, if ADC maps were created). That experiment may provide an alternative explanation for the condition in the postmortem brain, water could be in some kind of a gel state in differing patterns in the white matter and cortex.

With respect to the basal ganglion changes the noted high ADC values (1.16 to 1.43 ×10⁻³ mm²/s) at the rims of the lesions were consistent with presence of a relatively loose tissue. The values at the center parts were lower (0.61 to 0.66 ×10⁻³ mm²/s), and interpreting these together with the appearances on T1-and T2-weighted images, these could reflect presence of hemorrhagic products. Overall, all these lesions probably reflected different histopathological stages of a disease in the basal ganglion. With respect to the diagnosis of the condition, regarding the patient history, the age (10 months), and clinical findings, the condition was likely due to a mitochondrial disorder.

In conclusion, in the postmortem brain there is a prominent difference between the white and gray matter ADC values on diffusion MRI. The cortex is swollen compared to the white matter. These suggest that the conditions in the white matter leading to restriction of movement of water molecules are more severe than that in the cortex, and the swollen cortical tissue is looser with more mobility of water molecules. An alternative explanation for this is in the postmortem brain water could be in some kind of a gel state in differing patterns in the white matter and cortex.

**RÉFÉRENCES**