Patterns of pronounced gray-white differentiation on apparent diffusion coefficient (ADC) maps in patients with global brain injury

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Purpose

To determine what kind of disease could be shown by noting the accentuated gray-white differentiation on the apparent diffusion coefficient (ADC) maps and whether there are different patterns of this finding according to etiology of brain damage.

Methods and Materials

Patients

From December 2006 to Mar 2009, we prospectively collected MR images that showed accentuated gray-white differentiation on the ADC maps, and especially those ADC maps of those patients with hypoxic brain injury, brain death, hypoglycemia, status epilepticus and other toxic or metabolic encephalopathies and who were seen during our routine clinical practice. There were 19 patients (9 males and 10 females) with 20 MR images and their DWI or ADC maps showed pronounced gray-white differentiation. Their age ranged from 37 to 82 years (mean age: 53 years). The medical records of all 19 patients were retrospectively reviewed to evaluate their medical and neurologic statuses and the final clinical outcomes. Age-mated controls (n=10) whose brain MR demonstrated findings within the normal limits were included for comparison. Consent for MR imaging was obtained from a legally authorized representative, yet consent for this imaging study was waived. Our institutional review board approved this retrospective study.

MR images

The diffusion-weighted images were obtained using 1.5T or 3 T MR imaging systems (Signa Excite, GE Medical Systems, Milwaukee, WI; Sonata, Siemens, Erlangen, Germany) in all the patients. The DWI was obtained with a single-shot spin-eco echo-planar pulse sequence with two diffusion sensitivity values of 0 and 1000 s/mm² along all three orthogonal axes. The slice thickness and gap of the DWI was 3mm and 1 mm, respectively. Other brain MR images that included the spin-echo T1-weighted, fast spin-echo T2-weighted and fast fluid-attenuated inversion-recovery (FLAIR) images were obtained for nine patients. The MR imaging parameters were as follows: 450-466/12/2 (TR/TE/NEX) for the spin-echo T1-weighted images, 3666-4000/96-104/1-2/7 (TR/TEeff/NEX/echo train) for the fast spin-echo T2-weighted images and 5000-10000/110-155/2000/1/7 (TR/TEeff/TI/NEX/echo train) for the FLAIR images. MR angiography of the intracranial vessels was done with using the 3D time-of-flight (TOF) technique in eight patients. The contrast-enhanced MRA (n=3) or 3D TOF (n=5) images for the carotid vessel were also obtained.
Image and statistical analysis

We retrospectively evaluated the brain MR images, and if there were different patterns of the DWI and ADC maps for these patients with global brain injury. To quantitatively determine these patterns, we measured the ADC values at representative areas of the brain. Fifteen ROIs for each patient were obtained with manual drawing on the ADC map for assessing lesions in the following areas: the bilateral frontal cortexes and deep white mater (WM) at the level of the centrum semiovale (n=4), the bilateral frontal cortical and periventricular WM at the level of the lateral ventricle (n=4), the bilateral putamens in the basal ganglia (n=2), the bilateral thalami (n=2) and the bilateral cerebellar hemispheres at the levels of both the middle cerebral peduncle (n=2) and the mid portion of the splenium (n=1). The ADC values of the control subjects were also measured at the above mentioned areas of the brain.

All patients with global brain injury were divided into three groups based on the ADC decrease of the cerebral cortical and WM. The mean ADC values at all measured anatomical locations were statistically analyzed for each group and a control group. One way analysis of variance (ANOVA) was used to compare the mean values of the ADC at the each anatomic location of the three groups of patients and a control group, and the Turkey test was used for multiple comparisons.

Results

Patterns of the diffusion-weighted images and the apparent diffusion coefficient maps

In the patients with global brain injury, there were three different patterns of ADC decrease. We have defined these patterns, as a predominantly decreased ADC in the cerebral cortical area (pattern I), a decreased ADC in both the cerebral cortex and WM and a predominant decrease in the cerebral WM (pattern II), and a predominantly decreased ADC in only the cerebral WM (pattern III). Figure 1 show these patterns of the DWI and the ADC map.
Fig.: Figure 1. Patterns of accentuated gray-white differentiation on the diffusion-weighed image (DWI) and the apparent diffusion coefficient (ADC) map. Pattern I: A (DWI) and B (ADC map) in a 65-year-old man (case 1); Pattern II: C (DWI) and D (ADC map) in a 65-year-old man (case 2).
map) in a 38-year-old woman (case 11); Pattern III: E (DWI) and F (ADC map) in a 68-year-old man (case 20). Both patterns II and III have a 'T2-like ADC map', but different diffusion-weighted imaging.

References: E. Kim; Radiology, Samsung Medical Center, Seoul, KOREA, Republic of

Table 1 shows the patterns of the ADC decreases, the etiology, the time intervals between the brain insult and obtaining the MR images, the MR angiography and the prognosis or the final neurologic status for the patients with global brain injury.

Patterns I showed a decreased ADC and diffuse high signal intensity mainly in the cerebral cortical area (figure 2).

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**Fig.** Figure 2 A 53-year-old woman (case 6) underwent MR imaging 14 hours after septic shock. The DWI (A) and ADC map (B) shows pattern I. Intracranial (C) and neck (D) MR angiography demonstrates patent vessels.
References: E. Kim; Radiology, Samsung Medical Center, Seoul, KOREA, Republic of
Eight patients were included as showing pattern I. They suffered global hypoxic brain injury and their MR images were obtained 14 hours to 6 days (mean: 3.2 days) after the brain insults. The MR angiography obtained in one patient demonstrated patent intracranial arteries (figure 2).

Nine patients were classified as pattern II, and their DWIs showed diffuse high signals in the both the cerebral cortex and the WM. However, the ADC maps demonstrated lower signal intensity in the cerebral WM than that in the cerebral cortical area, and the ADCs resembled the T2-weighted image, the so-called T2-like ADC (figure 3).

Fig.: Figure 3 DWI (A) shows diffuse high signal intensity in the brain and the ADC map (B) resembles the T2-weighted image in a 55-year-old woman (case 10) who suffered cardiac arrest, and the DWI (A) and ADC map (B) obtained 3 days after brain insult. Time of flight intracranial MR angiography (C) and contrast-enhanced neck
angiography (D) demonstrate no intracranial arteries and prominent external carotid arteries, which suggests brain death.

**References:** E. Kim; Radiology, Samsung Medical Center, Seoul, KOREA, Republic of

Their etiologies were also global hypoxic brain injury. The time intervals from brain insult to MR imaging ranged from 2 day to 10 days (mean: 5.8 days) for the patients with pattern II. The MR angiography of five patients with pattern II revealed no intracranial vessels, suggesting brain death (figure 3). Case 8 and 9 was one patient with two different patterns of ADC decrease on the serial MR images. It is possible that a pattern 1 ADC decrease could evolve into a pattern 2 ADC decrease over time (figure 4).
**Fig.**: Figure 4 A (DWI) and B (ADC map) were obtained 37 hours after cardiac arrest in a 40-year-old man, and they reveal pattern I injury (case 8). However, the follow-up DWI (C) and ADC (D) map obtained 5 days after brain insult show a reversed
ADC map (pattern II injury) (case 9). The MR angiography obtained at this time demonstrates nonvisualization of the intracranial arteries (E and F).

References: E. Kim; Radiology, Samsung Medical Center, Seoul, KOREA, Republic of

In the pattern III group, the DWI showed high signal intensity in the cerebral WM and the ADC maps demonstrated low signal intensity in the cerebral WM, showing a T2-like ADC map. However, the signal intensity of the cerebral cortex on both the DWI and the ADC map appeared normal (figure 5).

Fig.: Figure 5 A 49 year-old woman (case 18) who suffered from severe hypoglycemia shows pure white matter injury on the DWI (A) and the ADC map (B) obtained 12 hours after the insult. The FLAIR images (C and D) that were obtained eight days after the hypoglycemic event demonstrate leukoencephalopathy.
References: E. Kim; Radiology, Samsung Medical Center, Seoul, KOREA, Republic of

There were three patients with profound hypoglycemia and their MR images were obtained 6 hours to 12 hours from brain injury. Two patients were seen to have patent intracranial vessels on MR angiography. The patient outcome of this pattern III group was the most favorable of all the patient groups.

Quantitative analysis of the ADC decreases in the patient groups and a control group

The mean ADC values of each anatomical area in the patient groups and a control group were tabulated in table 2. The mean ADC difference of the cerebral cortical area and the cerebral WM in the control group was \(40 \times 10^{-6}\) mm\(^2\)/s.

The absolute difference of the mean ADC values of the cerebral cortex and WM in patient-groups ranged from \(231 \times 10^{-6}\) mm\(^2\)/s to \(332 \times 10^{-6}\) mm\(^2\)/s. Pattern I showed a significantly lower mean ADC value in the cerebral cortical area, but a higher mean ADC value in the cerebral WM than those of the control group. Pattern II demonstrated the lowest mean ADC values in the majority of the measured anatomic areas, except the cerebral cortical area in the pattern I group. In this pattern II group, the cerebral WM and splenium showed more decreased ADC values than that of the cerebral cortical area, the basal ganglia and the thalamus. In the pattern III group, only the cerebral WM and the splenium showed decreased ADC values rather than an increased ADC value in the cerebral cortical areas.

Conclusion

It is important for radiologists to recognize that accentuated gray-white differentiation suggests global brain injury. Pattern I is cerebral cortical injury, and this suggests cortical laminar necrosis in hypoxic brain injury. Pattern II is cerebral cortical and white matter injury, and this is frequently seen in brain death, while pattern III is mainly white matter injury and this is especially found in hypoglycemic brain injury.

References


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