Introduction

Dural sinus thrombosis is an uncommon but occasionally critical disorder [1, 2]. Clinical diagnosis of dural sinus thrombosis is sometimes difficult because of various and nonspecific manifestations. Routine MRI [2, 3, 4, 5, 6, 7, 8] and magnetic resonance angiography [2, 9, 10] are useful tools for establishing the diagnosis. However, conventional magnetic resonance examinations are notable to distinguish between cytotoxic and vasogenic edema.

Diffusion-weighted MRI has been a recently established diagnostic method to evaluate stroke, especially hyperacute cerebral ischemia [11, 12, 13, 14]. Diffusion-weighted imaging is based on the random motion or diffusion of water molecules [15, 16], and can provide useful information for distinguishing between cytotoxic and vasogenic edema. The purpose of this study was to determine whether cytotoxic or vasogenic edema is more predominant in the affected cerebral parenchyma and assessing the time courses and prognosis of dural sinus thrombosis lesion. The studies on sixteen patients with dural sinus thrombosis who underwent diffusion-weighted MRI were retrospectively reviewed. The diagnosis was confirmed by digital subtraction angiography in 11 patients and magnetic resonance angiography in five patients. Diffusion-weighted images with echo-planar imaging were obtained using two or three b values, with the highest b value of up to 1,000 s/mm². A region of interest was placed on an area of abnormal signal intensity to calculate apparent diffusion coefficients (ADCs). Nine of the 16 patients had lesions with an increased ADC, whereas, three of these nine patients also had lesions with a decreased ADC. Among 11 patients who underwent initial MRI within 7 days of their last episode, eight had lesions with an increased ADC, of whom three had lesions mixed with both decreased and increased ADC areas. Follow-up studies of these three patients revealed the development of hemorrhagic infarction in two and subcortical hemorrhage in one. Vasogenic edema develops more predominantly and earlier in dural sinus thrombosis, though cytotoxic edema was also associated with the pathological changes in the early phase. Decrease of ADC value is presumed to reflect severe pathological conditions and indicate possible future development of infarction or hemorrhage.

Keywords Sinus thrombosis · Intracranial · MRI · Diffusion
apparent diffusion coefficients (ADCs) that indicate whether affected cerebral edema is of cytotoxic or vasogenic origin [17]. Hyperacute cerebral ischemia demonstrates a decline in ADC, which is presumed to be associated with cytotoxic edema. However, the changes in the findings on diffusion-weighted imaging and the changes in ADC values in relation to the disease progress of dural sinus thrombosis remain to be elucidated.

A few reports have dealt with diffusion-weighted imaging in patients with cerebral venous thrombosis [18, 19, 20, 21, 22, 23], but the results and conclusions are contradictory. Thus, the kind of associated edema in the affected cerebral parenchyma in such disorder is not established. Moreover, the time course and the prognosis of these conditions are not known well.

The purpose of this study was to determine whether edema affecting the cerebral parenchyma is of cytotoxic or vasogenic origin and to evaluate the time course and prognosis of dural sinus thrombosis and associated lesions in such patients.

**Methods**

Magnetic resonance studies of sixteen patients with dural sinus thrombosis who had undergone diffusion-weighted imaging were retrospectively reviewed. The study group consisted of eight men and eight women with a mean age of 53 years (range: 31–81 years). The diagnosis of dural sinus thrombosis was confirmed by digital subtraction angiography in 11 patients and magnetic resonance angiography in five patients. Magnetic resonance examinations were performed with a 1.5-T (14 patients) or a 1.0-T (two patients) superconductive magnetic resonance system. All patients had an unenhanced magnetic resonance examination including T1-weighted and T2-weighted images. Diffusion-weighted images with echo-planar imaging were obtained using two or three b values, with the highest b value up to 1,000 s/mm². Diffusion-weighted images were isotropically obtained in all but two patients, where they were anisotropically obtained. CT and angiography were referred to, as well as conventional MRI, to assess diffusion-weighted MRI findings. Follow-up studies were also reviewed.

We determined two time periods, namely, time after the onset and that after the last episode, to clarify the relationship between time course of signs and symptoms and ADC changes in dural sinus thrombosis. The time after the onset was defined as the time between the onset and a magnetic resonance examination. The time after the last episode was defined as the time between the last episode and a magnetic resonance examination. The time after the last episode was considered the time of the disease.

We placed a region of interest (ROI) on the abnormal-intensity area, avoiding hematomas, on T2-weighted or diffusion-weighted images, in order to calculate ADC values. The ROI was placed on cerebral parenchyma adjacent to the occluded sinus if there were no signal intensity changes on T2-weighted or diffusion-weighted images. We considered the areas with the maximum and minimum ADC as being the representative lesions when multiple areas of abnormal intensities were observed. In follow-up studies with diffusion-weighted imaging, an ROI was placed on the same areas used in the initial study. A control ROI was placed on normal cerebral parenchyma on the contralateral side. The ADC values were calculated, based on the following equation:

\[ \text{SI}/\text{SI}_0 = \exp(-b \cdot \text{ADC}) \]

where SI is the signal intensity in the pixel with diffusion gradient, SI₀ is the signal intensity without diffusion gradient and b is the b value. We considered as the normal range of ADC the mean ± 2SD of the ADC in the control area. We considered that cytotoxic edema affected the cerebral parenchyma when its ADC was smaller than the mean – 2SD of the control area, whereas vasogenic edema did so when its ADC was larger than the mean + 2SD of the control area.

**Results**

The patients' characteristics are summarized in Table 1. Figure 1 demonstrates the scatter plot of the ADC values versus the time after the onset or the time after the last episode. The mean ADC value (±SD) of the control areas in the 16 patients was 0.807 (± 0.060) × 10⁻³ mm²/s.

Ten of the 16 patients had cerebral parenchymal lesions with hyperintensity on T2-weighted images, and the remaining six showed no areas of abnormal signal intensity on T2-weighted images in their initial magnetic resonance examinations. Nine of the ten patients with hyperintense lesions on T2-weighted images had lesions with an increased ADC, and three of these nine also had lesions with a decreased ADC. The remaining one of the ten showed a normal range of ADC values. All six patients with normal T2-weighted images showed normal ranges of ADC values.

Tables 2 and 3 summarize ADC changes against signal intensity on T2-weighted images in the early phase of dural sinus thrombosis. Table 2 shows the changes in six patients who underwent the initial magnetic resonance examination within 7 days of the onset of dural sinus thrombosis, while Table 3 shows those of 11 patients who underwent the initial magnetic resonance examination within 7 days of their last episode. Nine of these 11 patients had cerebral parenchymal lesions with hyperintensity on T2-weighted images. Eight of the nine patients had lesions with total or partial areas of increased ADC, and three of these eight also had lesions partly with a decreased ADC. The remaining one of the nine showed a normal ADC value.

With respect to the 11 patients who underwent initial magnetic resonance examination within 7 days of their last episode, ten of the 11 underwent follow-up MRI and the remaining one of 11 had only a follow-up CT examination. In eight of the ten patients, follow-up diffusion-weighted images were obtained. Figure 2 demonstrates changes in the ADC value of lesions versus the time after the last episode. ADC values tended to return to the normal values in all except one patient.

As described above, three of the 11 patients had lesions showing both areas with decreased and increased ADC simultaneously on the initial MRI within 7 days of the last episode of the disease. Follow-up studies of these