CLINICAL ARTICLE

J Korean Neurosurg Soc 38: 23-27, 2005

Diffusion-weighted Imaging and Apparent Diffusion Coefficient Maps for the Evaluation of Pyogenic Ventriculitis

Hyeong Seok Kim, M.D.,[1] Jae Taek Hong, M.D.,[1] Sang Won Lee, M.D.,[1]
Byung Chul Son, M.D.,[1] Jae Hoon Sung, M.D.,[1] Moon Chan Kim, M.D.[2]

Department of Neurosurgery,[1] St. Vincent Hospital, The Catholic University of Korea, Suwon, Korea
Department of Neurosurgery,[2] Kangnam St. Marys' Hospital, The Catholic University of Korea, Seoul, Korea

Objective : The aim of this study is to assess the significance of an apparent diffusion coefficient(ADC) study for diagnosis of ventriculitis.

Methods : Seven patients with ventriculitis were enrolled in this study. Diffusion-weighted(DW) magnetic resonance images(MRI) and ADC maps in the dependent intraventricular collection, periventricular white matter and non-dependent cerebrospinal fluid(CSF) were obtained. The images and ADC data from the different lesions were compared.

Results : The DW MRI showed marked hyperintensity in the purulent pus lesion, and the corresponding ADC maps revealed prominent hypointensity and restricted ADC values compared with the non-dependent CSF and normal white matter.

Conclusion : The decreased ADC value and increased signal intensity of the dependent intraventricular fluid on the DW MRI show restricted water diffusion in the purulent fluid, which is indicative of a pyogenic ventriculitis diagnosis.

KEY WORDS : Pyogenic ventriculitis · Magnetic resonance imaging · Diffusion weighted imaging · Apparent diffusion coefficient.

Introduction

Ventriculitis is a rare intracranial infection in adults that has been referred to as ependymitis, ventricular empyema, pyocephalus, and ventriculitis[15]. Pyogenic ventriculitis is a subset of ventriculitis, which is characterized by the presence of suppurative fluid in the ventricles. It is important to recognize pyogenic ventriculitis because its signs and symptoms may be subtle, its course can be indolent but lethal, and it may be the cause of meningitis, which is difficult to eradicate[15,16]. The case numbers of pyogenic ventriculitis are likely to increase due to the increasing incidence of bacterial meningitis over the last 30 years as a result of nosocomial infections[15].

Although computed tomography(CT) and magnetic resonace image(MRI) are the mainstays of neuroimaging in cases of adult meningitis, few reports of sporadic cases have documented the CT and MRI findings of ventriculitis[7]. Because the major obstacle in the effective treatment of ventriculitis is a failed or delayed diagnosis[15], this study aimed to improve the diagnosis of this disease entity. The main goal was to examine the ability of diffusion-weighted(DW) MRI and apparent diffusion coefficient(ADC) maps to the diagnosis of pyogenic ventriculitis in order to hasten the recognition of this grave intracranial infection, and permit a prompt, appropriate treatment.

Materials and Methods

Patient characteristics

This was a retrospective study of an MR examination performed on 7patients (3women and 4men [aged 5~78; mean 49]) with pyogenic ventriculitis who were admitted to our institution from 2002 to 2003. Ventriculitis was caused by a ventricular extension of a cerebral abscess in two patients, an iatrogenic shunt infection in three, subdural empyema in

• Received : September 16, 2004 • Accepted : November 30, 2004
• Address for reprints : Jae Taek Hong, M.D., Department of Neurosurgery, St. Vincent Hospital, The Catholic University of Korea, 93-6 Ji-dong, Paldal-gu, Suwon 442-723, Korea Tel : +82.31-249-7190, Fax : +82.31-245-5208, E-mail : jatagi15@paran.com

Table 1. Summary of the causative organisms and patient's characteristics in the seven ventriculitis patients

Case	Age/Sex	Cause	Organism	ADC value (x10^{-3} mm^2/sec)		
				Pus	Normal CSF	WM
1	66/F	Abscess	S. aureus	0.57	2.87	1.02
2	5/M	Shunt infection	P. aeruginosa	0.76	3.65	1.43
3	78/M	Shunt infection	S. epidermidis	0.66	3.46	1.35
4	59/F	Abscess	S. aureus	0.78	2.72	1.27
5	67/M	Shunt infection	A. Baumannii	0.91	3.12	1.39
6	61/F	Subdural empyema	CNS	0.54	3.25	1.29
7	7/M	EVD	S. aureus	0.59	3.57	1.15

M : male, F : female, ADC : apparent diffusion coefficient, WM : white matter, CSF : cerebrospinal fluid, S. aureus : Staphylococcus aureus, P. aeruginosa : Pseudomonas aeruginosa, S. epidermidis : Staphylococcus epidermidis, A baumannii : Acinetobacter baumannii, CNS : coagulase negative staphylococcus, EVD : external ventricular drainage

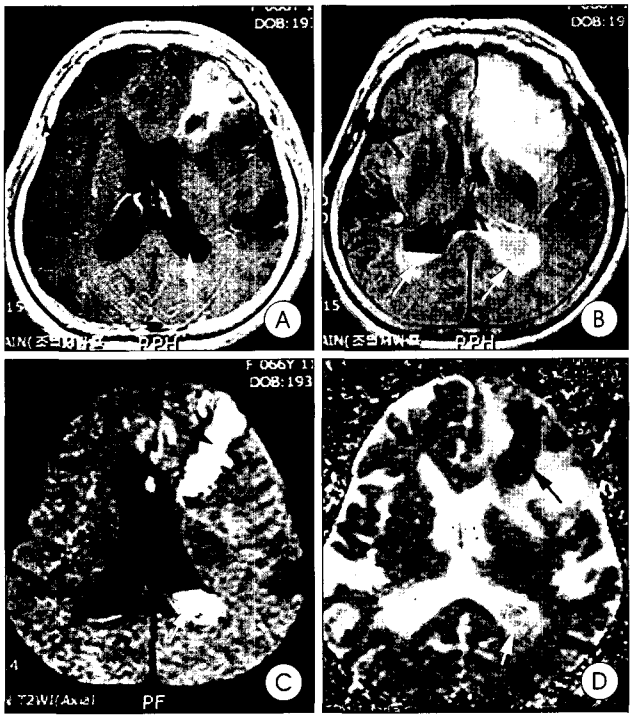

Fig. 1. Case 1. A 66-year-old patient with diabetes initially presented to an outside facility with headache and confused mentality. Staphylococcus aureus grew on cerebrospinal fluid culture. A : T1-weighted magnetic resonance(MR) image obtained after gardolinium administration showing a cystic, ring-enhancing cavity with peripheral hypointensity in left frontal region. Purulent material in the dependent portion of the left lateral ventricle is demonstrated (arrow). B : FLAIR MR image showing loculation of the ventricle with periventricular signal abnormality and pus-cerebrospinal fluid(CSF) level (white arrows) in the dependent portion of the ventricle. C : Diffusion-weighted MR image showing a fluid-pus level (white arrow) in the occipital horn of the lateral ventricle. Diluted pus is uniformly hyperintense and bright as much as the abscess cavity (black arrow). D : Apparent diffusion coefficient(ADC) map depicting hypointense diluted intraventricular pus (white arrow) that is intermediate in brightness compared with that of the CSF and that of the abscess cavity (black arrow).

one, and in one patient, the cause was believed to be multiple procedure of external ventricular drainage(EVD). The presence of pyogenic ventriculitis and the causative organism were demonstrated by a cerebrospinal fluid(CSF) study and MR studies including DW imaging and ADC maps were obtained from all patients. The causative organisms were varied (Table 1).

MR imaging

A 1.5-T scanner (Gyroscan NT; Philips medical systems, Best, Netherlands) was used for MR imaging. The conventional MR imaging protocol included (a) axial T1-weighted spin-echo (500/10[repetition time (TR) msec/echo time (TE) msec]), (b) axial T2-weighted fast spin-echo (4500/100[TR msec/TE msec]), and (c) axial FLAIR (10000/400/2200[inversion time]). The parameters of conventional MR imaging were a 256×192 matrix, a 23-cm field of view, and a 5mm/2mm slice thickness/intersection gap. Single-shot, spin-echo, echo-planar DW image sequences were obtained by applying the diffusion gradients in three orthogonal directions for each slice, with two diffusion weightings (b value=0 and 900 or 1000sec/mm^2). Isotropic DW image was generated on-line by averaging the three orthogonal-axis images. After the lesion had been detected, post-processing to obtain the ADC maps were completed using online software that ran a pixe-by-pixel analysis. All the ADC values are expressed in 10^{-3} mm^2/sec. After reviewing the entire film sequence, two of the authors placed several region of interest(ROI) in the central part of the lesion in multiple cuts for the ADC measurements. The size of the ROI was chosen in order to avoid the inclusion of periventricular edema. For all patients, the control values were measured in the healthy white matter and non-dependent ventricular CSF. A mean value was calculated for the ADC in the lesion, the normal white matter, and the non-dependent ventricular CSF. For all the statistical tests, a difference was defined as being significant when the probability value was less than 0.05.

Results

The characteristics of seven ventriculitis patients were summarized in Table 1. The DW MRI and corresponding ADC maps were obtained from all patients. Ventriculitis and its associated brain abscesses demonstrated strong hyperintense signals particularly in the occipital horn of the lateral ventricle, which is in contrast to the hypointense signal of the CSF. At the same level, a hypointense area, which is corresponded to the brain abscess, was found in the ADC maps adjacent to the hyperintense CSF signal (Fig. 1). A weak hyperintense area corresponding to the edema surro-

Fig. 2. Case 2. A 5-year-old boy with purulent ventriculitis after resection of posterior fossa medulloblastoma and ventricular shunt placement. A : Non-enhancement computed tomography scans of hydrocephalus thirteen day after shunt placement showing ventricular debris (white arrow) in occipital horn of the lateral ventricle. B : Diffusion-weighted magnetic resonance image showing pus in dependent position of occipital horns and marked hyperintense signal (arrows) compared with cerebrospinal fluid and brain parenchyma. C : Corresponding apparent diffusion coefficient(ADC) maps showing the reduced ADC value of dependent purelent material of occipital horn.

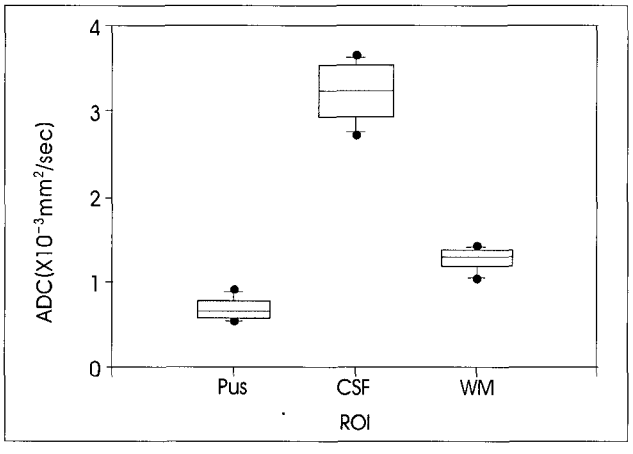

Fig. 3. Vertical box plots showing different apparent diffusion coefficient(ADC) values of the separate region of interest. ADC value of pus in the ventricle is significantly lower than that of cerebrospinal fluid and white matter. Data represent the mean ADC value in all patients in the respective group.

unded the ventricular pus on the DW images (Fig. 2). Low ADC values were found in case of abscess and ventriculitis (mean of 0.58 and 0.69, respectively). In the one patient with a subdural empyema, a mean ADC value of 0.9 (range 0.83-0.98) was calculated.

In all ventriculitis patients, the surrounding periventricular edema was visualized as a weak hyperintense area on the DW images, which is similar to the perilesional edema of the abscesses. The mean ADC values for the normal white matter and non-dependent CSF was 1.27 (range 1.02-1.43) and 3.23 (range 2.72-3.65) respectively. The ADC values for the ventricular pus and abscesses were similar but significantly lower than those for the normal white matter and non-dependent CSF. The statistical differences between the ADC value of the ventricular pus and those of the white matter, and non-dependent CSF were significant (Fig. 3).

Discussion

Pyogenic ventriculitis is a rare intracranial infection that occurs most often as a complication of a brain abscess rupture into the ventricle or after a neurosurgical procedure such as a craniotomy, EVD or a ventriculo-peritoneal shunt[7,11,13,15]. And also, unsuspected ventriculitis might be a source of a persistent infection and the therapeutic failure in the management of meningitis, which can be fatal[17]. In particular, gram-negative bacteria might be resistant to standard antibiotics. The early treatment of ventriculitis is crucial, because fatal neurological damage can occur, even in patients in whom the infection is ultimately eradicated. Subsequent studies have shown that delayed CSF sterilization is directly related to neurological deterioration in ventriculitis patients[6,9]. One series that examined the reasons for the treatment failure of ventriculitis cited the delayed diagnosis to consider as being a significant cause[7,15]. Therefore, the detection of ventriculitis is important to ensure an early and appropriate treatment because the presence or absence of ventriculitis might affect the management decisions.

The relative lack of fever and the severe presenting symptoms of ventriculitis might highlight the predilection of immunocompromised patients for ventriculitis, including those suffering from alcoholism, cirrhosis, or diabetes and patients having recently undergone a neuro-surgical procedure. Usually, these patients are critically ill. Therefore, a noninvasive method for the detection or follow-up of ventriculitis is highly desirable, because it could pote-ntially avoid the morbidity associated with invasive methods of diagnosis[17]. Recently, Fukui et al. described the MR and CT imaging features of 17patients with pyogenic ventriculitis[7]. An irregular configuration of the ventricular debris, hydrocephalus, periventricular hypointensity, ependymal contrast enhancement, and the signs of meningitis have been reported in many patients.

The clinical picture, along with the laboratory findings, might assist in narrowing the diagnosis, but a radiological examination has become invaluable for confirmation. Usually, drainage of the CSF by any means is essential, so the appropriate antibiotics can be administered to treat the cultured organisms. However, lumbar puncture in the setting of a

cerebral abscess is potentially detrimental, particularly when the intracranial pressure is elevated, in which case the diagnosis based on CT or MR imaging findings becomes crucial[17].

Echoplanar DW MR imaging has become a widely accepted method for examining stroke, because it allows the detection of an infarct at a much earlier stage than either CT or conventional MR imaging[1,18]. The reduced ADC value can be used as the first visible indicator of tissue abnormality on MR imaging, which has been shown to be associated with the failure of energy-dependent ion homeostasis and cytotoxic cell swelling[8]. The diffusivity of water is affected in a wide range of other pathologies. Therefore, DW MR imaging has been shown to be useful for evaluating a myriad of disease processes, including cerebral infarction, tumors, abscesses, demyelinating disease, and vertebral compression fractures[8,10,14,19,22]. Ebisu et al. first reported on DW imaging and ADC calculations as being potentially helpful in the diagnosis of a brain abscess[5]. They reported a case of a cerebral abscess in which the DW images demonstrated hyperintensity in the abscess cavity (in vivo) as well as in the aspirated abscess fluid (in vitro). Both of these findings corresponded to a low ADC value. The ADC in the extracellular space is dictated by a tortuosity factor, which represents the length of the path of a molecule traversing in a medium. Under normal condition, water molecules easily traverse through the extracellular space via random Brownian motion[17,20]. In the setting of a brain abscess or organized pus, the movement of water molecules is influenced by the content of the abscess or pus, which consists of varying amounts of inflammatory cells, microorganisms, and proteins. All of these components are large macromolecules[21]. Many investigators reported that the ADC value is inversely proportional to the protein concentration[17]. Consequently, these macromolecules retard the diffusion of water molecules within an abscess cavity. In addition, water molecules in an abscess are bound to carboxyl, hydroxyl, and amino groups on the surfaces, which further limit their translational movement[4]. These factors most likely explain the imaging features of an abscess cavity along with other purulent pathologies (high signal intensity on DW images and low ADC values).

With respect to the DW MR imaging findings of ventriculitis, Fukui et al. reported that diffusion in a purulent intraventricular fluid was not restricted in two cases. However, they did not report the ADC values for these cases[7]. Pezzullo et al. recently reported three patients with pyogenic ventriculitis, who were diagnosed prospectively as a result of the signs of markedly restricted water diffusion on the DW MR imaging[15]. However, the number of cases was so small, and the data was not conclusive. In our seven cases with ventriculitis from various origins, there was restricted diffusion in the dependent purulent intraventricular fluid, which showed high signal intensity on DW images and low ADC values. In the patient, in whom a cerebral abscess had ruptured into the left lateral ventricle, the abscess core showed hyperintensity on the DW images with corresponding ADC hypointensity. These results confirmed the findings reported by other groups. It should be noted that although the intraventicular pus had the same degree of hyperintensity on the DW images as that of the abscess core, it had variable signal intensity on the corresponding ADC maps (intermediate to hypointense signal). This finding was attributed to a gradient of concentrated macromolecules, cells and cellular debris, and microorganisms within the pus that were diluted by the CSF to a greater extent and were better depicted in the right ventricle. This indicated that the ADC maps, which depicted regional variation in ADC values, were more sensitive in showing subtle change in the content or concentration of the pus than DW imaging.

The ADC value can be used for the non-invasive method of follow-up the pyogenic ventriculitis patient using this characteristic where the viscosity and content of the pus can be monitored using this method during the therapeutic period. Therefore, ADC maps are important for extracting the quantitative information for diagnosis or follow-up the purulent processes in the brain, which is lacked in DW images. However, another interesting finding in the literature is that in the case of an intracerebral hemorrhage, the DWI and ADC maps showed various types of signal intensity in the different stages of hematoma[12]. In the cases with hyperacute and late subacute hematoma, the signals at the center of the hematoma are hyperintense in the DW images. Considering that pyogenic ventriculitis usually occurs after a neurosurgical procedure such as a craniotomy, the EVD in the cases of intraventricular hemorrhage(IVH), it is important in distinguishing an IVH from pyogenic ventriculitis. In these cases, the MR imaging or CT findings would be helpful. In particular, periventricular hyperintensity on FLAIR images and the ependymal contrast enhancement on MR images would not be expected in cases of IVH, and a marked signal loss in the blood products would be expected on the gradient-echo T2-weighted MR imaging in IVH cases[2,3].

Conclusion

DW imaging with ADC mapping is useful for screening and diagnosing pyogenic ventriculitis due to the specific signal intensity profile and the ADC counting of the ventricular pus that shows restricted water movement. Therefore, the finding of restricted diffusion in patients with pyogenic

ventriculitis suggests the presence of intraventricular pus. The limitations of this study include the lack of a histopathological confirmations and the small number of cases. Although a complete understanding of the underlying biophysical basis may require further studies using a larger population, these results suggest that a better understanding of the DW images and ADC maps are useful in characterizing pyogenic ventriculitis for therapeutic planning and follow-up.

• Acknowledgement
This study was financially supported by a clinical research grants from St. Vincent Hospital and the Catholic Medical Center, Korea for the year 2004.

References

1. Ahlhelm F, Reith W : Modern diagnosis in acute cerebral infarct. Diffusion weighted imaging and ADC (apparent diffusion coefficient) calculations. **Nervenarzt 73** : 736-744, 2002
2. Bakshi R, Kamran S, Kinkel PR, Bates VE, Mechtler LL, Belani SL, et al : MRI in cerebral intraventricular hemorrhage : analysis of 50 consecutive cases. **Neuroradiology 41** : 401-409, 1999
3. Bakshi R, Kamran S, Kinkel PR, Bates VE, Mechtler LL, Janardhan V, et al : Fluid-attenuated inversion-recovery MR imaging in acute and subacute cerebral intraventricular hemorrhage. **AJNR Am J Neuroradiol 20** : 629-636, 1999
4. Castillo M : Imaging brain abscesses with diffusion-weighted and other sequences. **AJNR Am J Neuroradiol 20** : 1193-1194, 1999
5. Ebisu T, Tanaka C, Umeda M, Aoki I : Principles and clinical applications of diffusion weighted echo planar MR imaging. **Nippon Rinsho 55** : 1742-1747, 1997
6. Eholie SP, Boni N, Aoussi E, Konan A, Orega M, Koffi Adonis L, et al : Neurosurgical complications of purulent meningitis in the tropical zone. **Neurochirurgie 45** : 219-224, 1999
7. Fukui MB, Williams RL, Mudigonda S : CT and MR imaging features of pyogenic ventriculitis. **AJNR Am J Neuroradiol 22** : 1510-1516, 2001
8. Guzman R, Barth A, Lovblad KO, El-Koussy M, Weis J, Schroth G, et al : Use of diffusion-weighted magnetic resonance imaging in differentiating purulent brain processes from cystic brain tumors. **J Neurosurg 97** : 1101-1107, 2002
9. Hader WJ, Steinbok P : The value of routine cultures of the cerebrospinal fluid in patients with external ventricular drains. **Neurosurgery 46** : 1149-1155, 2000
10. Herneth AM, Guccione S, Bednarski M : Apparent diffusion coefficient : a quantitative parameter for in vivo tumor characterization. **Eur J Radiol 45** : 208-213, 2003
11. Hur CW, Kim SH, Kim SW, Chang CH, Choi BY, Cho SH : External ventricular drainage system with long subcutaneous tunnel. **J Korean Neurosurg Soc 35** : 88-90, 2004
12. Kang BK, Na DG, Ryoo JW, Byun HS, Roh HG, Pyeun YS : Diffusion-weighted MR imaging of intracerebral hemorrhage. **Korean J Radiol 2** : 183-191, 2001
13. Lee JH, Lee KH, Hong SK : Intraventricular pefloxacine therapy for a cerebral ventriculitis by enterobacter aerogenes : case report. **J Korean Neurosurg Soc 29** : 126-130, 2000
14. Nadal Desbarats L, Herlidou S, de Marco G, Gondry-Jouet C, Le Gars D, Deramond H, et al : Differential MRI diagnosis between brain abscesses and necrotic or cystic brain tumors using the apparent diffusion coefficient and normalized diffusion-weighted images. **Magn Reson Imaging 21** : 645-650, 2003
15. Pezzullo JA, Tung GA, Mudigonda S, Rogg JM : Diffusion-weighted MR imaging of pyogenic ventriculitis. **AJR Am J Roentgenol 180** : 71-75, 2003
16. Rana AK, Wardlaw JM, Armitage PA, Bastin ME : Apparent diffusion coefficient(ADC) measurements may be more reliable and reproducible than lesion volume on diffusion-weighted images from patients with acute ischaemic stroke-implications for study design. **Magn Reson Imaging 21** : 617-624, 2003
17. Rana S, Albayram S, Lin DD, Yousem DM : Diffusion-weighted imaging and apparent diffusion coefficient maps in a case of intracerebral abscess with ventricular extension. **AJNR Am J Neuroradiol 23** : 109-112, 2002
18. Rohl L, Sakoh M, Simonsen CZ, Vestergaard-Poulsen P, Sangill R, Sorensen JC, et al : Time evolution of cerebral perfusion and apparent diffusion coefficient measured by magnetic resonance imaging in a porcine stroke model. **J Magn Reson Imaging 15** : 123-129, 2002
19. Romano A, Bozzao A, Bonamini M, Fasoli F, Ferrante M, Floris R, et al : Diffusion-weighted MR Imaging : clinical applications in neuroradiology. **Radiol Med 106** : 521-548, 2003
20. Rusakov DA, Kullmann DM : Geometric and viscous components of the tortuosity of the extracellular space in the brain. **Proc Natl Acad Sci U S A 95** : 8975-8980, 1998
21. Sener RN : Diffusion MRI findings in neonatal brain abscess. **J Neuroradiol 31** : 69-71, 2004
22. Tomczak R, Wunderlich A, Gorich J, Brambs HJ, Rilinger N : Brain abscesses in diffusion-weighted imaging(DWI)-comparison to cystic brain tumors. **Radiologe 43** : 661-664, 2003