Elevated diffusion anisotropy in gray matter and the degree of brain compression

Clinical article

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Object. For several decades, clinicians have predicted intraparenchymal brain pressure or brain tissue compression indirectly based on the degree of distortion of the midline structures (midline shift) and ventricle wall (ventriculomegaly) observed on conventional MRI. However, this method has several limitations. Diffusion tensor imaging (DTI) is a novel MRI technique that can provide information about the microstructural properties of compressed tissue. In this study, the authors evaluated whether DTI can precisely define the degree of tissue compression in patients with chronic subdural hematoma (CSDH).

Methods. The study sample consisted of 18 patients (mean age 71 years, 10 men and 8 women) with unilateral CSDH and 12 age-matched volunteers. Diffusion tensor imaging results were acquired before and after the surgical irrigation in the CSDH group. Subdural pressure during the operation was also measured. Fractional anisotropy (FA) values were evaluated at several locations, including the gray matter.

Results. The FA values of the gray matter, especially in the caudate nucleus and putamen, were increased in the patients with CSDH compared with the control group. The change in FA data before and after surgery (ΔFA) correlated with the degree of tissue compression evaluated by measurement of the subdural pressure. Furthermore, the increased FA values in patients with CSDH decreased after surgery.

Conclusions. These findings indicate that FA values of the gray matter, especially in the caudate nucleus and putamen, may be important markers of tissue compression. The assessment of FA values of the gray matter will result in a new, less-invasive diagnostic technique to evaluate the degree of brain compression.

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Key Words • diffusion tensor imaging • fractional anisotropy • chronic subdural hematoma • gray matter • brain compression

Brain tissue compression is a major source of symptoms in various intracranial diseases, including space-occupying lesions, brain edema and hydrocephalus. The severity of the compression reflects the degree of symptom intensity in patients and is directly associated with surgical indications and the outcome in many intracranial diseases.10,18 Many types of diagnostic devices, including conventional CT and MRI, have been developed to assess the degree of compression appropriately. Using these conventional imaging techniques, we can speculate about the compression based on the presence of macroscopic structural changes such as midline shift, ventriculomegaly, obliterated cisterns and sulci,12,18 but it is impossible to exactly evaluate physical phenomena such as compression or ICP, even currently. A possible additional problem is that these radiological features may not always correspond to the pathological changes, because the age of a patient and the disease type may influence the radiological findings.5,12,13 These limitations may lead to misdiagnosis and inappropriate treatment. For this reason, invasive studies such as lumbar puncture...
or ICP monitoring are needed. Some authors reported that the ONS diameter on MRI correlates with the ICP, although the relationship between ONS diameter and brain tissue compression is unclear. There has been considerable interest in developing a more sensitive imaging method to evaluate brain compression.

Over the past several decades, ICP monitoring methods have been used to help assess the degree of brain compression. These methods have been commonly used in many intracranial diseases, such as traumatic brain injuries, normal pressure hydrocephalus, pediatric hydrocephalus, arachnoid cysts, and craniosynostosis. With the advances in monitoring technology, the safety and accuracy of measurements have improved, allowing more widespread use in many situations. However, infections and surgical complications have limited the length of use and applicability of ICP monitoring. Another drawback is that although space-occupying masses compress the nearby brain tissue more than the distant areas, the ICP monitoring method cannot evaluate the distribution of brain compression efficiently, but can evaluate only the total pressure inside the skull.

Diffusion tensor imaging is a novel MRI technique that can provide information on the microstructural properties of white matter. Diffusion tensor imaging makes use of diffusion-sensitizing gradients applied in 6 or more noncollinear directions to determine the full diffusion tensor. Diffusion tensor imaging can extract the principal diffusivities, the mean diffusivity, and the FA. These diffusion data provide information about the white matter microstructure that cannot be evaluated using conventional MRI. Furthermore, DTI can distinguish the compression characteristics of the brain, which demonstrates that increased anisotropy might be related to white matter compression. Our previous study showed that the diffusion anisotropy of the caudate nucleus increased due to compression associated with ventricular dilation in cases of chronic hydrocephalus, suggesting that elevated values of diffusion anisotropy in the gray matter may be used to assess the degree of compression.

Conventional MRI in CSDH often shows severe deformation of the brain cortex with a midline shift. In some cases, the subdural pressure is not so high (≤ 15 cm H2O), despite significant structural changes, probably because of extra capacity made available by brain atrophy due to traumatic injury, stroke, or infectious disease. In contrast, severe intracranial and/or subdural pressure often affects the irreversibility of higher brain function of some patients with CSDH. In this study, we focused on the association of patients’ symptoms and FA, the value of which was probably changed as a result of compression of the gray matter in cases of CSDH. The main purpose of the present study was to determine whether the increasing anisotropy of gray matter is related to the degree of brain compression.

Methods

Study Population

Data of patients with CSDH treated at Kobari General Hospital between July 2009 and October 2010 were analyzed in this prospective, single-center study. Inclusion criteria were as follows: 1) unilateral CSDH, requiring surgical evacuation, 2) safely applied MRI before and after the operation, and 3) informed consent obtained from both the patient and at least 1 member of the patient’s family. Exclusion criteria were as follows: 1) recurrent CSDH, 2) accompanying coagulation disorder, and 3) a history of CSDH, stroke, severe brain injury, brain tumor, or infectious disease in the brain. In this study phase, 20 patients with unilateral CSDH were initially treated in the hospital, and 18 patients were included (mean age 71 ± 9 years, 10 men, 8 women). One of the 20 patients was excluded because his condition was too severe to perform MRI. Another patient was excluded because of atypical CSDH symptoms. The data of 12 healthy volunteers (4 men, 8 women) were also examined for comparison. None of the volunteers had any intracranial morphological abnormalities (on MRI), neurological disease, history of severe head trauma, or psychiatric disorder. The average age of the volunteers was 67 ± 9 years, and there was no statistically significant age difference between the patients and volunteers (p > 0.05, Mann-Whitney U-test and unpaired Student t-test).

The protocol was approved by the institutional review board of Kobari General Hospital before the study was begun. Written informed consent for study participation was obtained from each patient and the patient’s family members, as well as from the volunteers who participated in this clinical study; all patients and volunteers were assigned identification numbers before analysis to protect their privacy. We also obtained consent to present the data gathered in this study at academic meetings and to publish the data in any form.

Surgical Procedure for CSDH

All patients underwent surgical evacuation by bur hole surgery. Subdural pressure was measured using a manometer with a 23-gauge needle before opening the dura mater during surgery. The surgical evacuation was performed under the same local anesthesia and intravenous sedation.

Image Acquisition and DTI Analysis

Magnetic resonance imaging was acquired on a 1.5-T MR unit (Achieva Nova-Dual; Philips) with a maximum gradient strength of 66 mT/m. Diffusion tensor imaging was performed using a multisection, single-shot, spin echo–echo planar imaging sequence: TR 6796 msec, TE 73 msec, FOV 230 mm, matrix 112 × 112 interpolated to 128 × 128, slice thickness 3 mm without a gap, number of slices 50, number of acquisitions 3, b values 0 and 1000 seconds/mm2 in 15 different directions, and total scan time 5 minutes 46 seconds. Optic nerve sheath diameters were measured on thin-slice, fat-saturated, coronal T2-weighted images: TR 3000 msec, TE 120 msec, FOV 150 mm, matrix 256 × 179, and slice thickness 3 mm with a 0.3-mm gap. The sequences consisted of spin-echo T1-weighted MRI (TR 593 msec, TE 12 msec), fast spin-echo T2-weighted MRI (TR 4427 msec, TE 100 msec),
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and FLAIR imaging (TR 8000 msec, TE 100 msec, TI 2300 msec).

In each case of the patient group, preoperative MRI was performed 1 day before the operation or on the operation day. Postoperative MRI including DTI was performed 7 days after the operation. In each case of the healthy volunteer group, DTI study was performed once.

Diffusion tensor imaging analysis was performed as described by Basser and Pierpaoli. The data were processed using the software programs Volume-One and a diffusion tensor visualizer (Department of Radiology, University of Tokyo, Japan) for DTI analysis. Volumes of interest of uniform size were set anatomically in several locations: the 2 points of the corpus callosum (the splenium and genu), head of the caudate nucleus, the thalamus, putamen, posterior limbs of the internal capsule, and corona radiata. Concurrently, FA, mean diffusivity, and the eigenvalues of the diffusion tensor \((\lambda_1, \lambda_2, \lambda_3)\) at each point were calculated for objective evaluation with the software. Volumes of interest were selected bilaterally in at least 3 sections in which anatomical regions could be identified. The measured volume at each point was a sphere of approximately 3.6 mm in diameter, as this size was the optimal size of each region. The diffusion property of each position was obtained by averaging the data from the 3 volumes of interest.

Figure 1 is an example of volume of interest selection in a patient subject. To set volume of interest anatomically, we used FA maps, color-coded maps, and b0 maps. We selected the posterior limbs of the internal capsule, corona radiata, putamen, the head of the caudate nucleus, and thalamus on the axial map (Fig. 1D–H, respectively). The corpus callosum was selected on the median sections of sagittal color-coded maps; it was marked in red, and 2 points were chosen (Fig. 1B and C).

After obtaining DTI data, we extracted the FA maps and morphological data (b0 maps). Then, the FA maps were modified to emphasize regions showing FA values in the range of 0.20 to 0.40 as red-to-yellow colored areas, as we believe the areas represented by red are associated with the highly compressed regions. We made fusion images from these data using the program MRicro (www.mricro.com; Rorden and Brett).

Clinical Information and Other Imaging Features

In this study we analyzed clinical information, such as symptoms and subdural pressure during the surgical evacuation, and the imaging data, including FA values, the degree of midline shift, and the diameter of the ONS. At the same time as MRI was obtained before and after the operation, the intensity of symptoms was measured according to the following scales: the cognitive state by the MMSE,7 the degree of disability or dependency in daily activities by the mRS,24 and the degree of paresis.

![Fig. 1. Example of an axial FLAIR image (A) on MRI and volume of interest selections (B–H) in a patient with CSDH. The FLAIR image shows CSDH on the right side compressing the ipsilateral brain tissue. The genu (B) and the splenium (C) of the corpus callosum are indicated in a median section of a sagittal color-coded map. The posterior limb of the internal capsule (D), the corona radiata (E), putamen (F), head of the caudate nucleus (G), and thalamus (H) are indicated in axial color-coded maps (B–F), a b0 map (G), and an FA map (H).](image)
by an MMT. The midline shift of the septum pellucidum was assessed on axial T1-weighted imaging (Fig. 2 left). The diameters of the ONS were defined by measuring the outer diameter of the subarachnoid space just behind the optic globe (Fig. 2 right).

Statistical Analysis

Statistical analysis was performed using the Student t-test (paired and unpaired) for continuous variables, where the differences of mean values between the groups and within each group were observed. To determine the significant differences between the groups, including intermittent variables or categorical variables, we used the Mann-Whitney U-test (unpaired) or Wilcoxon rank-sum test (paired). To assess the correlation between each factor and the subdural pressure, we used Pearson linear correlative analysis and/or Spearman correlative analysis for DTI data, and rank correlative methods for measuring the intensity of symptoms. Probability values < 0.05 were considered statistically significant. The statistical software package SPSS (version 18; SPSS, Inc.) was used for statistical analysis.

Results

Demographic and Clinical Information

In 18 patients enrolled in this study, the lesion was located on the left side in 5 cases and on the right side in 13 cases. All patients had 1 or more typical symptoms of CSDH, such as paresis, gait disturbance, or dementia. All patients showed improvement of symptoms after surgery. In all cases, postoperative MRI showed that the volume of CSDH markedly decreased. Only 2 patients experienced recurrence of CSDH, 1 month after postoperative analysis.

Diffusion Tensor Imaging Analysis

Fractional anisotropy maps of a representative CSDH case are shown in Fig. 3. Figure 4A summarizes the mean FA values for each point of the gray matter of the patients before and after the CSDH operation, compared with the control group. The FA values of the caudate nucleus and putamen on the hematoma side before the surgery were higher than those of the control group, and similar changes were observed in the putamen on the contralateral side. At all points of the gray matter, FA values after surgery decreased significantly when compared with those before surgery.

Fig. 2. Axial T1-weighted MRI showing the way to measure midline shift of the septum pellucidum (left). As a measurement of the left ONS diameter, the outer diameter of the subarachnoid space just behind the optic globe is measured using coronal T2-weighted MRI (right).

Fig. 3. Magnetic resonance images of a representative case before and after surgical evacuation. Axial (A) and coronal (B) FLAIR maps show a massive subdural hematoma on the right side. An FA map (C) and modified FA map (D) show slightly increased FA values preoperatively in the caudate nucleus and putamen (arrows) compared with the contralateral side. Postoperatively, the FA map (E) and modified FA map (F) revealed resolution of the lesion. Fractional anisotropy values of the lesion returned to the normal range (arrows).
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In contrast to the gray matter, most points of the white matter showed no remarkable state changes in all the compared data (Fig. 4B). Only the FA value of the corona radiata significantly decreased after surgery compared with the value before surgery.

To further investigate the origin of elevated FA in gray matter, we analyzed mean diffusivity and eigenvalues ($\lambda_1, \lambda_2, \lambda_3$) of the patients before and after the CSDH operation (Fig. 5). Areas of increased FA showed no net change in mean diffusivity. The $\lambda_3$ eigenvalues after surgery were significantly increased in both the putamen and caudate nucleus compared with those before the surgery. The $\lambda_1$ eigenvalues after surgery significantly decreased in the putamen and had a tendency to decrease in the caudate nucleus.

**Correlation With Subdural Pressure**

To investigate the most significant data with the best correlation to direct subdural pressure measurement, we evaluated the correlation between each factor and the subdural pressure, as summarized in Table 1. The subdural pressure correlated with various FA data at the CSDH side, including preoperative FA value of the putamen ($r = 0.59, p = 0.010$), $\Delta$FA of the caudate nucleus ($r = 0.69, p = 0.002$), and $\Delta$FA of the putamen ($r = 0.67, p = 0.002$). In combination of $\Delta$FA values, the pressure was more strongly correlated with the sum of preoperative FA of the caudate nucleus and putamen ($r = 0.60, p = 0.009$) and the sum of $\Delta$FA of the caudate nucleus and putamen ($r = 0.80, p < 0.001$) than with other combinations. There was no region in the white matter showing an FA value correlated with the pressure with high reproducibility (detailed data not shown).

The subdural pressure also correlated with the sum of $\Delta$FA of the caudate nucleus and putamen at the contralateral side ($r = 0.50, p = 0.036$). On the other hand, the pressure was not associated with any data from conventional MRI or clinical symptoms, although midline shift, ONS diameters, and $\Delta$mRS had some tendency to be associated with the pressure. Figure 6 shows the relationship between the subdural pressure and the FA values of the caudate nucleus (Fig. 6A), putamen (Fig. 6B) and the sum of $\Delta$FA on the CSDH side (Fig. 6C). Figure 7 shows the relationship between the sum of $\Delta$FA of the caudate nucleus and putamen on the CSDH side and the clinical data of the patients. The sum of $\Delta$FA values correlated with the $\Delta$mRS values (Fig. 7B) as well as with the subdural pressure (Fig. 6C), and it did not correlate with other data, including the degree of midline shift (Fig. 7A, C, and D). Moreover, multiple regression analysis showed that the subdural pressure was the only factor associated with the sum of $\Delta$FA ($p = 0.0007$); $\Delta$mRS ($p = 0.15$), $\Delta$MMSE ($p = 0.18$), $\Delta$MMT ($p = 0.25$), the degree of midline shift ($p = 0.46$), and ONS diameter ($p = 0.90$) were not significant factors associated with $\Delta$FA or with subdural pressure.

**Fig. 4.** Graphs of mean FA values for each point of the gray (A) and white matter (B) in preoperative, postoperative, and control (Cont) groups. A: In the preoperative group, all regions indicate significantly higher FA values compared with postoperative data. Compared with the control data, the caudate nucleus (CN) on the CSDH side and the putamen (Pt) on both sides show higher FA values with statistical significance. B: Most points show no remarkable state changes among the 3 groups, and only the FA values of the corona radiata (CR) in the postoperative data are significantly decreased compared with the preoperative data. CC = corpus callosum; Contra = contralateral side; IC = internal capsule; Th = thalamus. *$p < 0.05$. 
Discussion

In this study, the FA values of the gray matter increased in the patients with CSDH compared with the control group. The AFA correlated with the degree of tissue compression evaluated by measurement of the subdural pressure and AmRS. Elevation of FA in the gray matter diminished after the CSDH surgery. These findings indicate that the FA values of the gray matter, especially in the caudate nucleus and putamen, may be important markers of tissue compression.

Previous reports have shown that increased FA values indicate compression characteristics of the brain tissue under specific conditions, including the characteristics of the pyramidal tract in children with obstructive hydrocephalus, and white matter compressed by a brain tumor. The diffusion anisotropy of the caudate nucleus increased, probably due to compression associated with ventricular dilation in our cases of chronic hydrocephalus. Along the compressed fiber system, the diffusivity increases parallel to the fibers but decreases perpendicular to the fibers, leading to the overall increase of FA values, reflecting the compression of the fiber bundle. In this study, we found FA elevation in the gray matter without a change in mean diffusivity values. The λ₁ eigenvalues (indicating diffusivity parallel to the fibers) decreased and λ₃ (indicating diffusivity perpendicular to the fibers) increased in the same areas after surgery. These changes might reflect stretching of the fibers before surgery to be more linearly aligned, resulting in fewer obstacles to diffusion and faster diffusion. This diffusion change looks similar to that of white matter reported previously.

In this study, we found that the FA elevation in the gray matter correlated with the subdural pressure more precisely than that in the white matter. We hypothesize that the pathological changes caused these alterations. The compressed white matter tissue revealed enlarged extracellular spaces (so-called edema), probably causing the pseudodecrease (or pseudonormalization) of increased FA values in these regions. On the other hand, compressed gray matter tissue showed normal dimensions of extracellular space and this characteristic

### Table 1: Results of regression analysis to evaluate the associations with subdural pressure

<table>
<thead>
<tr>
<th>Factors</th>
<th>r Value</th>
<th>p Value</th>
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<td>caudate nucleus hematoma</td>
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<td>ΔFA</td>
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* p < 0.05, Pearson linear correlation analysis.
might prevent the pseudonormalization of FA by brain compression. The significant decrease of FA values in various regions of white matter was shown in chronic hydrocephalus cases of our previous study.\textsuperscript{15} In contrast, most regions of the white matter in CSDH cases showed no decrease of FA values. Past DTI studies reported that decreased FA in white matter was generally associated with neuronal degeneration or brain edema.\textsuperscript{14,21} It is likely that degenerative and edematic changes in CSDH were less significant than in hydrocephalus with CSF leak. We continue to question why FA values of the thalamus did not increase significantly, similar to other lesions of the gray matter. We speculate that pathological structures of the thalamus differ from those of the caudate nucleus and putamen, because average FA values of the thalamus were much higher than those of the caudate nucleus and putamen.

**Fig. 6.** Scatterplots showing the relationship between subdural pressure and $\Delta$FA of the caudate nucleus (CN) on the CSDH side (A), the putamen (B), and the sum of $\Delta$FA of the caudate nucleus and putamen (C).

**Fig. 7.** Scatterplots showing the relationships between the sum of $\Delta$FA of the caudate nucleus and putamen on the CSDH side and the $\Delta$ value of clinical symptoms measured by the MMSE (A), mRS (B) and MMT (C). The relationship between the sum of $\Delta$FA and the degree of midline shift is also shown (D).
putamen in the control group. A pathological feature of thalamus, which is much richer in white matter bundles, could influence a behavior closer to the white matter.

Based on the results of the FA elevation in the deep gray nuclei, superficial gray matter in the cortical ribbon is theoretically also a good target for this study. The changes would be much more profound because space-occupying masses are commonly located on the surface of the brain. However, these lesions in the shape of "ribbon" are not appropriate for a quantitative volume-of-interest method due to contamination of white matter components. Another analysis method must be employed for the evaluation of the cortical ribbon.

In our study, some of the contralateral FA values were also decreased after surgery. These preoperative elevations of contralateral FA values were observed in only the patients with very high subdural pressure (detailed data not shown). In addition, the degree of elevated FA and subdural pressure correlated with each other. Therefore, we believe that the FA elevation in the bilateral gray matter occurred in cases with severe brain compression.

There has been only 1 previous report of CSDH evaluated by DTI. Yokoyama et al.27 reported DTI findings in 26 cases before and after surgery. In this report, preoperative FA values in the pyramidal tracts of the cerebral peduncles on the CSDH side decreased, and they improved after surgery, although FA values of the other areas were not evaluated. The reversible decrease of FA correlated with motor weakness in the patients with CSDH. The authors concluded that these anisotropic changes were caused by the reversible distortion of neuron fibers and vasogenic edema due to CSDH. Therefore, we believe that the elevation of FA in the gray matter may be more sensitive in the case of brain compression than that in the white matter affected by various factors, including brain edema.

One limitation of this study was potential inaccuracy in the measurement of FA values. In this study, we applied a strictly quantitative volume-of-interest method using various anatomical data with high reproducibility to avoid inaccuracy. However, theoretically, severe compression may shorten the distance between other anatomical regions near the gray matter, leading to contamination by partial volume effect. To avoid this issue completely, further studies using higher-resolution imaging are needed. On the other hand, any measurement errors in the white matter would have little influence on our results, because the white matter regions are bigger anatomical areas with clearer borders than the gray matter.

In this study, multivariate analysis showed that subdural pressure was the only factor associated with ΔFA. Other data, including ΔmRS, were not significant factors, although univariate analysis showed a mild association between ΔFA and ΔmRS. It is not surprising that there was no association between ΔFA and other clinical data, because recovery of the neuropsychiatric activities in CSDH patients was strongly affected by patients' preoperative status, rather than by neuroimaging data, as in our previous study.8 Also in the present study, ΔmRS score correlated with preoperative mRS score (r = 0.5851) more strongly than with the other measurements (detailed data not shown).

To our regret, our finding may not help to determine an indication or a timing of surgery in the case of ordinary CSDH, because neither the actual subdural pressure nor the FA is related to clinical outcome. To demonstrate the effectiveness for surgical decision making, we need larger population studies with CSDH patients to assess the correlation between FA elevation and long-term functional outcome.

Our finding may help in the development of a new method to assess brain compression. Elevated FA in the gray matter may be correlated with the degree of compression in the case of CSDH. Therefore, the assessment of FA values of the gray matter will be a new, less-invasive diagnostic technique for evaluating the degree of brain compression. However, this preliminary study raises questions about whether our findings can be generalized to other intracranial diseases with brain compression, such as traumatic brain injury, brain tumor, and stroke. Further research is needed in the form of larger-scale studies of patients with CSDH or other intracranial diseases.

Conclusions

Fractional anisotropy values of the gray matter increased in the CSDH group, and the elevation was correlated with the subdural pressure. The assessment of FA values of the gray matter will be a new, less-invasive diagnostic technique for evaluating the degree of brain compression. Further research of the diagnostic abilities of this technique using a large number of patients is needed.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Ishikawa, Osuka. Acquisition of data: Ishikawa, Osuka, Matsushita, Saotome. Analysis and interpretation of data: Ishikawa, Osuka, Matsushita, Saotome. Drafting the article: Ishikawa, Osuka, Zaboronok. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Ishikawa. Statistical analysis: Ishikawa, Osuka. Study supervision: Matsumura.

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References


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