INTRODUCTION

Cerebral venous thrombosis (CVT) is responsible for less than 1% of all strokes, although recent evidence has indicated that the incidence of CVT among adults is higher than previously reported (1-4). The improvement of non-invasive imaging modalities has increased the detection rate and improved the prognosis of patients with CVT (5). Magnetic resonance imaging (MRI) and magnetic resonance venography (MRV) are the most important modalities for the diagnosis of CVT (6-12). Diagnosis by MRI is based on abnormal signal intensities within the thrombosed venous segment, which are caused by altered blood flow and hemoglobin degradation products of the thrombus (13, 14). However, in many patients with CVT, MRI-based diagnosis is still difficult, because CVT exhibits subtle and/or variable alterations of signal intensity over time on non-enhanced MRI, and may be easily confused with normal flow signal artifacts (13-16). Although gadolinium-enhanced MRI and MRV can be effective, they have economic and scan time disadvantages, and the gadolinium causes side effects.

Gradient-recalled echo (GRE) images are the most sensitive and specific sequence for the diagnosis of CVT among non-enhanced MRI sequences (10, 14). The red blood cells in the thrombus produce characteristic findings of low signal and/or blooming of the thrombus. However, the frequency of the findings decreases over time; eventually, the low signal changes into
an iso- or a high signal during follow-up, despite the presence of the thrombus (14, 17-19). Furthermore, the diagnostic performance of each MRI sequence of patients with CVT during anticoagulation treatment has not been reported.

This study compared the diagnostic performance of routine MR sequences including gadolinium-enhanced T1-weighted imaging (Gd-enhanced T1WI), fluid-attenuated inversion recovery (FLAIR) imaging, diffusion-restriction imaging (DWI) with the apparent diffusion coefficient (ADC), GRE, and Gd-enhanced T1WI to determine which is the best sequence for the evaluation of cases of CVT (excluding cortical venous thrombosis), and to determine if Gd-enhanced T1WI is necessary for follow-up examinations. Follow-up examinations of cerebral venous sinus thrombosis (CVST) were of particular interest.

MATERIALS AND METHODS

This study was approved by our Institutional Review Board (Ulsan University Hospital, University of Ulsan Collage of Medicine, Ulsan, Korea, UUH 2015-10-010-001). Informed consent was waived for this retrospective study.

Patients

This retrospective study examined the MRI findings of 58 cases at our institution that were confirmed to be CVST between January 2006 and March 2016. Forty-five cases were excluded because of the following: 1) not all follow-up sequences were included (22 cases), 2) there was no follow-up MRV (17 cases), 3) only the presence of cortical venous thrombosis was detected (3 cases), or 4) the presence of coexisting dural arteriovenous fistula was detected (3 cases). Thus, 13 cases were included in this study (Fig. 1).

MRI and MRV Protocols

All MR images including the initial and follow-up examinations were performed using a Achieva 3T scanner (Philips, Amsterdam, the Netherlands) with a 16-channel head coil (SENSE NeuroVascular coil, Koninklijke Philips N.V.). SENSE (SENSitivity encoding, Koninklijke Philips N.V.) was used as a parallel imaging method. The MR sequences were T1WI, FLAIR, DWI with ADC, GRE, and Gd-enhanced T1WI. The sequences were customized as follows: T1WI [repetition time (TR): 695 ms, echo time (TE): 15 ms, scan time: 252.5 s, matrix size: 224 × 180, flip angle: 65° degrees], FLAIR (TR: 11000 ms, TE: 125 ms, scan time: 198 s, matrix size: 352 × 208, flip angle: 120° degrees, inversion time: 2800 ms, P reduction factor: 2), DWI (TR: 5000 ms, TE: 63 ms, scan time: 60 s, matrix size: 128 × 128, flip angle: 90° degrees, P reduction factor: 2), GRE (TR: 708 ms, TE: 16 ms, scan time: 145.9 s, matrix size: 256 × 204, flip angle: 18° degrees, P reduction factor: 2), and Gd-enhanced T1WI (TR: 569 ms, TE: 10 ms, scan time: 222.9 s, matrix size: 256 × 193, flip angle: 90° degrees). The field of view was defined as 250 × 250 mm for DWI and 230 × 210 mm for all other sequences. The section thickness was set to 5.0 mm for all sequences, with a gap of 1.0 mm and 25 slices. The total MRI acquisition time was approximately 20 min.

The acquisition parameters of 3 dimensional (3D) phase contrast MRV (3D PC; patients 4, 5, and 13) and 4 dimensional (4D) time-resolved MRV [4D time-resolved MR angiography with keyhole (TRAK); all other patients] were as follows; 3D PC (TR: 18 ms, TE: 6.5 ms, scan time: 437 s, matrix size: 256 × 195, flip angle: 10° degrees, PC velocity: 15 cm/s, field of view: 250 × 250 mm, P reduction factor: 2.5), and 4D TRAK (TR: 29
ms, TE: 1.1 ms, scan time: 72.5 s, matrix size: 252 × 252, flip angle: 25° degrees, field of view: 250 × 250 mm).

Image Analysis

Two neuroradiologists (YCW: 19 years of experience; SHC: 17 years of experience) independently reviewed the initial and follow-up MR sequence images in random order. Both reviewers were blinded to the patients’ medical data and MRV findings. There was no case with a discrepancy in interpretation of the thrombosed dural venous sinus (DVS) segment on the MRV images.

Only cases involving the DVS were included in this study; cases of cerebral cortical venous only or deep venous thrombosis only were excluded. None of the cases involved thrombosis in the antero-inferior group of the dural sinuses (cavernous sinus, superior and inferior petrosal sinuses, clival venous plexus, and sphenoparietal sinus). The involved DVS segments were categorized as the superior sagittal sinus, inferior sagittal sinus, straight sinus, right transverse sinus, left transverse sinus, right sigmoid sinus, and left sigmoid sinus.

The diagnostic criterion was the presence of a continuous portion of signal change within the DVS wall compared to the adjacent normal DVS segment. For the T1WI sequence, the abnormal signal intensity of a positive case lacked the normal flow void signal intensity. For the FLAIR sequence, the high-intensity signal lacked the normal flow void signal intensity. For the GRE sequence, the characteristic strong dark signal was considered positive. For the Gd-enhanced T1WI sequence, a positive result was considered a non-enhancing low-intensity signal with DVS wall enhancement. For the DWI sequence, a positive result was considered a bright, high-intensity signal with a corresponding low ADC value. In cases of discrepancy, the final decisions were made through consensus. A confirmed CVST diagnosis was based on MRV (3D phase contrast MRV or 4D time-resolved MRV) and conventional angiography as the reference modalities.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows (version 21.0; IBM Corp., Armonk, NY, USA) and R software (version 3.2.5; R Foundation for Statistical Computing, Vienna, Austria). The sensitivity, specificity, and accuracy for each MR sequence was calculated for each sequence using the Diagnosis Med package. The McNemar test was used to evaluate the diagnostic performance of each sequence; MRV was used as the reference standard. Kappa analyses were performed to evaluate the inter-observer agreement. Differences with a p-value < 0.05 were considered significant.

RESULTS

Clinical Findings

The patients included 2 women and 11 men; the mean age was 42.15 years (range: 15–73 years) (Table 1). The primary symptoms at the initial diagnosis included headache (10/13), one-side weakness (2/13), and seizure (1/13). The mean duration from symptom onset to the first MRI was 6.8 days (range: 1–21 days), all patients underwent MRIs during the acute stage (within 7 days of onset, 7 cases) or the subacute stage (within 8–30 days, 6 cases). Twelve patients had confirmed CVST based on the MRV findings, and one patient (No. 12) was confirmed using conventional angiography.

All patients were hospitalized and received short-term intravenous heparin treatment (international normalized ratio target: 1.5) before switching to long-term oral warfarin treatment (international normalized ratio target: 2–3).

Thirteen patients underwent follow-up MRI examinations (8 patients underwent one, 1 patient underwent two, and 4 patients underwent three follow-up examinations, respectively). A total of 22 follow-up MR examinations were performed during the acute stage (within 7 days from onset, 2 cases), the subacute stage (8–30 days, 6 cases), and the chronic stage (after 30 days, 14 cases). The mean interval between the initial and follow-up examinations was 90 days (range: 6–282 days).

CVT on Initial MRI Sequences

The initial MRI images identified 34 thrombosed DVS segments in 13 patients, which included the transverse sinus (n = 11), superior sagittal sinus (n = 11), sigmoid sinus (n = 9), inferior sagittal sinus (n = 2), and straight sinus (n = 1). Superficial cortical venous thrombosis was diagnosed in 6 patients (46%).

The diagnostic performances of the initial MRI sequences are shown in Table 2. The most sensitive MR sequence for the diagnosis of CVT was Gd-enhanced T1WI (82%). GRE was the most sensitive of the non-enhanced sequences (77.4%). T1WI (69.6%),

FLAIR (34.4%), and DWI (18.8%) were less sensitive. All MR sequences had high specificities, from 94.9% to 100%.

The most accurate sequence was Gd-enhanced T1WI (92.9%). GRE (90.5%) was the second most accurate sequence, followed by T1WI (88.6%), FLAIR (73.6%), and DWI (71.4%). Gd-enhanced T1WI had the best inter-observer agreement (k = 0.916); GRE (k = 0.886) had the second highest inter-observer agreement. The inter-observer agreements of the other MR sequences were as follows: DWI (k = 0.846), T1WI (k = 0.845), and FLAIR (k = 0.728).

### Table 1. Clinical Characteristics of 13 Patients with Dural Venous Sinus Thrombosis

<table>
<thead>
<tr>
<th>No.</th>
<th>Sex/Age</th>
<th>Primary Symptom</th>
<th>Clinical Stage/Duration (Days)</th>
<th>Thrombosed Segments</th>
<th>Associated MR findings</th>
<th>Recanalization on F/U MRV</th>
<th>No. of F/U MRIs</th>
<th>Total F/U Period (Days)</th>
<th>Mean F/U Period (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M/51</td>
<td>Headache</td>
<td>Subacute (14)</td>
<td>LT, LS</td>
<td>Venous infarction</td>
<td>No (LT, LS)</td>
<td>3</td>
<td>345</td>
<td>115</td>
</tr>
<tr>
<td>2</td>
<td>M/57</td>
<td>Headache</td>
<td>Acute (4)</td>
<td>IS, St, LT, LS</td>
<td></td>
<td>Partial (LT, LS), Complete (IS, St)</td>
<td>1</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>3</td>
<td>M/51</td>
<td>Headache</td>
<td>Acute (1)</td>
<td>SS, LT, LS</td>
<td>Venous infarction</td>
<td>No (LT), Complete (IS, LS)</td>
<td>1</td>
<td>135</td>
<td>135</td>
</tr>
<tr>
<td>4</td>
<td>M/28</td>
<td>Headache</td>
<td>Subacute (10)</td>
<td>SS, RT, RS</td>
<td></td>
<td>Complete (SS, RT, RS)</td>
<td>1</td>
<td>208</td>
<td>208</td>
</tr>
<tr>
<td>5</td>
<td>M/73</td>
<td>Headache</td>
<td>Subacute (10)</td>
<td>SS, IS, LT, LS</td>
<td>No (SS, IS, LT, LS)</td>
<td>Complete (IS, SS, LT, LS)</td>
<td>3</td>
<td>272</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>M/32</td>
<td>Seizure</td>
<td>Acute (1)</td>
<td>SS</td>
<td>Venous infarction</td>
<td>Complete (SS)</td>
<td>1</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>7</td>
<td>M/43</td>
<td>Headache</td>
<td>Acute (1)</td>
<td>SS, RT, RS</td>
<td>Venous infarction</td>
<td>Partial (SS), Complete (RT, RS)</td>
<td>2</td>
<td>163</td>
<td>81.5</td>
</tr>
<tr>
<td>8</td>
<td>M/23</td>
<td>Headache</td>
<td>Acute (1)</td>
<td>SS, RT</td>
<td></td>
<td>Complete (SS, RT)</td>
<td>1</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>9</td>
<td>M/35</td>
<td>Lt. side weakness</td>
<td>Subacute (21)</td>
<td>SS, RT</td>
<td>Venous infarction</td>
<td>Complete (SS, RT)</td>
<td>3</td>
<td>298</td>
<td>99</td>
</tr>
<tr>
<td>10</td>
<td>M/71</td>
<td>Rt. side weakness</td>
<td>Acute (3)</td>
<td>SS, LT, LS</td>
<td>SAH</td>
<td>Partial (SS, LT, LS)</td>
<td>3</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>M/41</td>
<td>Headache</td>
<td>Acute (3)</td>
<td>SS, RT, RS</td>
<td>SAH, SDH</td>
<td>Partial (SS, RT, RS)</td>
<td>1</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>F/28</td>
<td>Headache</td>
<td>Subacute (10)</td>
<td>SS</td>
<td>Venous infarction</td>
<td>Complete (SS)</td>
<td>1</td>
<td>282</td>
<td>282</td>
</tr>
<tr>
<td>13</td>
<td>F/15</td>
<td>Headache</td>
<td>Subacute (9)</td>
<td>SS, LT, LS</td>
<td>Venous infarction</td>
<td>Complete (SS, LT, LS)</td>
<td>1</td>
<td>127</td>
<td>127</td>
</tr>
</tbody>
</table>

Complete = complete recanalization, Duration = days from symptom onset to first MRI, F = female, F/U = follow-up, IS = inferior sagittal sinus, LS = left sigmoid sinus, LT = left transverse sinus, M = male, MRI = magnetic resonance imaging, No = no recanalization, Partial = partial recanalization, RS = right sigmoid sinus, RT = right transverse sinus, SAH = subarachnoid hemorrhage, SDH = subdural hemorrhage, SS = superior sagittal sinus, St = straight sinus

### Table 2. Per-Segment Performances of Initial Brain Magnetic Resonance Sequences for the Detection of Dural Venous Sinus Thrombosis

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
<th>Kappa Value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRE</td>
<td>77.4</td>
<td>98.1</td>
<td>90.5</td>
<td>0.886</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>FLAIR</td>
<td>34.4</td>
<td>94.9</td>
<td>73.6</td>
<td>0.728</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>DWI</td>
<td>18.8</td>
<td>100.0</td>
<td>71.4</td>
<td>0.846</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>T1WI</td>
<td>69.6</td>
<td>97.9</td>
<td>88.6</td>
<td>0.845</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Gd-En T1WI</td>
<td>82.0</td>
<td>98.2</td>
<td>92.9</td>
<td>0.916</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

**DWI** = diffusion-weighted imaging, **FLAIR** = fluid-attenuated inversion recovery, **Gd-En T1WI** = gadolinium-enhanced T1-weighted imaging, **GRE** = gradient-recalled echo, **T1WI** = T1-weighted imaging

### Table 3. Per-Segment Performances of Brain Magnetic Resonance Sequences for the Detection of Dural Venous Sinus Thrombosis During Follow-Up

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
<th>Kappa Value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRE</td>
<td>15.6</td>
<td>100.0</td>
<td>76.4</td>
<td>0.806</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>FLAIR</td>
<td>55.6</td>
<td>95.7</td>
<td>84.5</td>
<td>0.836</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>DWI</td>
<td>22.2</td>
<td>99.1</td>
<td>77.6</td>
<td>0.902</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>T1WI</td>
<td>48.2</td>
<td>97.7</td>
<td>85.7</td>
<td>0.388</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Gd-En T1WI</td>
<td>55.3</td>
<td>99.0</td>
<td>87.1</td>
<td>0.815</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

**DWI** = diffusion-weighted imaging, **FLAIR** = fluid-attenuated inversion recovery, **Gd-En T1WI** = gadolinium-enhanced T1-weighted imaging, **GRE** = gradient-recalled echo, **T1WI** = T1-weighted imaging
CVT on Follow-up MRI Sequences

The follow-up MRI examinations revealed that 18 segments of 9 patients were completely recanalized and 9 segments in 4 patients were partially recanalized, based on MRV. Despite anticoagulant treatment, no changes were observed in 7 segments of 3 patients (Table 1).

The overall diagnostic performances of all sequences except FLAIR and DWI decreased during follow-up (Table 3). The most sensitive sequence was FLAIR (55.6%); Gd-enhanced T1WI (55.3%) was the second most sensitive, followed by T1WI (48.2%); DWI (22.2%) and GRE (15.6%) had relatively low sensitivities.

All MR sequences had high specificities (from 95.7% to 100%). The most accurate sequence was Gd-enhanced T1WI (87.1%), which also had high inter-observer agreement (k = 0.815). Among the non-enhanced follow-up sequences, T1WI (85.7%) was the most accurate sequence, but the inter-observer agreement was the lowest (k = 0.388). FLAIR had high accuracy (84.5%) and the second highest inter-observer agreement (k = 0.836). The accuracies of DWI (77.6%) and GRE (76.4%) were slightly lower. DWI had the best inter-observer agreement (k = 0.902). The inter-observer agreements of GRE and T1WI were lower (k = 0.606, k = 0.388, respectively).

![Fig. 2. Images of a 51-year-old man with acute left transverse sinus thrombosis (3 days). Note the susceptibility artifact, which is low signal and blooming (white arrows) on gradient-recalled echo imaging (A) and the empty delta sign (black arrows) in the left transverse sinus on Gd-enhanced T1-weighted imaging (B). No signal change is observed in the left transverse sinus (black arrows) compared to the normal right transverse sinus on fluid-attenuated inversion recovery (C). No diffusion restriction is observed in the left transverse sinus (white arrows) on diffusion-weighted imaging (D). Dural venous sinus thrombosis is confirmed as the filling defect in left transverse and sigmoid sinuses on gadolinium-enhanced 4 dimensional magnetic resonance venography (E).](image-url)
DISCUSSION

In the present study, Gd-enhanced T1WI was the most sensitive and specific MR sequence for the detection of CVST at an early stage. The inter-observer agreement of Gd-enhanced T1WI was the highest compared to other sequences that do not use a contrast agent. Unlike contrast-enhanced sequences, overall non-enhanced MR sequences are less sensitive due to variables or subtle changes in the signal intensity of the venous thrombus (15, 16, 20, 21). Among the non-enhanced sequences, GRE was the most sensitive and specific for the detection of CVST at the early stage. The thrombus showed characteristic low signal and/or blooming on GRE images, especially during the acute stage, in accordance with the results of other studies (14, 17-19). Rela-

Fig. 2. (continued) Images of a 51-year-old man with left transverse sinus thrombosis during follow-up (12 days). The patient underwent follow-up brain magnetic resonance imaging including MRV 12 days after the first examination due to aggravation of the headache. Note the susceptibility artifact on gradient-recalled echo (F) and typical empty delta sign in the left transverse sinus on Gd-enhanced gadolinium-enhanced T1-weighted imaging (G) are not observed (black arrows). The high signal intensity (black arrows) on fluid-attenuated inversion recovery (H), and high signal intensity indicating diffusion restriction (black arrows) in the left transverse sinus on diffusion-weighted imaging (I). Dural venous sinus thrombosis is confirmed as the filling defect in the left transverse and sigmoid sinuses on follow-up gadolinium-enhanced 4 dimensional MRV (J).
MRV = magnetic resonance venography
tively low sensitivities were reported for T1WI, FLAIR, and DWI. The lowest sensitivity was reported for DWI, which exhibited transient signal modifications within the thrombosed DVS due to the progressive change of the thrombus (22-24).

During the follow-up, Gd-enhanced T1WI and GRE images had decreased diagnostic performances compared to the initial imaging. Although Gd-enhanced T1WI images provided the best diagnostic performance during both the initial and follow-up examinations, the sensitivity of the method decreased during follow-up. The decrease may have been due to the signal changes of the thrombus from iso-signal in the acute stage to high signal in the subacute and chronic stages on T1WI. The signal changes of the thrombus were due to extracellular and intracellular methemoglobin in the evolving hyalinizing thrombus in the subacute stage (14); in chronic stage, it was thought to be related to the vascularized connective tissue of a chronic thrombus (13, 14, 25).

In a previous study (26), a magnetic resonance black-blood thrombus imaging (MRBTI) technique (3D variable flip angle turbo spin echo) was proposed as a diagnostic image technique due to its high diagnostic accuracy and the feasibility of quantification of the volume of the cerebral venous thrombosis in the early stage. The authors stated that although the chronic thrombosis did not have a short T1 relaxation time and exhibited isointensity on T1WI, the adequate suppression of the blood signal on MRBTI can readily detect the isointense chronic thrombus. However, we did not examine the 3D variable flip angle turbo spin echo images in this study.

Among the non-enhanced sequences, the GRE images had a high sensitivity in the acute stage, but had the lowest sensitivity in follow-up examinations. Among the thrombosed DVS segments within the characteristic GRE signal on the initial MRI (25 of 34 segments), 23 segments eventually lost that signal during follow-up, which is likely related to changes in the thrombus. Similarly, previous studies have revealed reduced follow-up sensitivity for GRE during the chronic stage (14). Leach et al. (14) reported a decreased GRE signal in 25% of cases of chronic thrombosis, which they attributed to removal of blood breakdown products in the thrombus during the chronic stage by intense macrophage activity. Our results were consistent with those findings.

FLAIR had a low sensitivity at the early stage and increased sensitivity during follow-up examinations compared to other MR sequences (from 34.4% to 55.6%). Interestingly, of 23 segments that lost their characteristic GRE signal during follow-up, 8 developed a new FLAIR high-intensity signal (4 cases each in the subacute and chronic stages) (Fig. 2). Those changes may be caused by the lysis of red blood cells in the CVST, as deoxyhemoglobin conversion into extracellular methemoglobin leads to a shorter T1 relaxation time and a prolonged T2 relaxation time, which generates an intense FLAIR signal (14). Unlike cases of brain parenchymal hemorrhage, this conversion may be affected by the conditions in the thrombosed DVS.

All sequences had high initial and follow-up specificities. The inter-observer agreement of the initial evaluation was generally better, although a higher follow-up agreement was observed for FLAIR. Our results also indicate that follow-up DWI sequences had a slightly increased sensitivity, although these sequences had a low diagnostic value due to the limited ability to visualize the thrombus. Similar results were observed in previous studies (10, 21-23). Nevertheless, DWI may be useful for cases with negative findings when other sequences are used to evaluate abnormal findings associated with CVT, such as parenchymal infarction (22, 23).

Gadolinium-enhanced 4D MR venography is the best MR study for confirmation of a thrombosis in the DVS in initial examinations. During follow-up examination of the anticoagulation treatment, MRV may be still necessary due to the relatively low sensitivities of the MR sequences. When there is thrombosis on Gd-enhanced T1WI, MRV may not be necessary, and anticoagulation treatment can be continued. As loss of the characteristic GRE signal does not necessarily reflect recanalization of the CVT during follow-up, it may be helpful to consider high signal change on FLAIR for the remaining thrombus in patients who cannot tolerate the contrast agent.

There were several limitations of this study. The first was related to image interpretation. Although the reviewers aimed to review the DVS segments of each MR sequence image separately, other MR sequence findings of the same DVS segment could have affected the interpretation of ambiguous MR sequence images. Moreover, parenchymal abnormalities due to CVST, such as venous infarction or hemorrhage, could also make the reviewer easily find CVST.

The second type of limitation was in the assessment of diag-
nostic performance. Similar to previous studies, the sample size was small, in particular because only patients who had undergone both the initial and follow-up MR examinations in the single center were included. Furthermore, we only included cases of CVST in this study; cases of cortical venous or deep venous thrombosis were excluded. Moreover, we did not compare the diagnostic performance within the control groups.

Third, the DVS is a continuous structure, so if a thrombus exists in the continuous segments (such as in the ipsilateral transverse and sigmoid segments), it is not an independent lesion. In this study, we considered each DVS segment as a separate lesion even if the thrombus was continuous. However, statistically, it could cause data clustering.

In conclusions, Gd-enhanced T1WI had the best diagnostic performance for CVST in both initial and follow-up MR examinations in the present study. Overall, the non-enhanced MR sequences showed relatively lower diagnostic performance compared to Gd-enhanced T1WI. Of non-enhanced MR sequences, GRE had the best diagnostic performance for CVST at the acute stage. During follow-up, the diagnostic performance of GRE decreased due to the loss of the characteristic low signal due to evolution of the thrombus. FLAIR showed increased sensitivity, as a high intense signal of CVST developed during follow-up. Therefore, Gd-enhanced T1WI is necessary for follow-up studies of CVST. If the patient cannot tolerate contrast agents, the use of FLAIR for remaining CVST may be helpful.

Acknowledgments
This study was supported by a grant from the Bracco image Korea.

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Diagnostic Performance of MRI Sequence for CVT

뇌정맥동혈전의 추적 검사에서 MRI Sequence의 진단적 가치 비교

최지은 · 원영철 · 박경민 · 권지현 · 김욱주 · 권운정 · 최성훈

목적: 뇌정맥동혈전의 추적 검사에서 각각의 magnetic resonance imaging (이하 MRI) sequence의 진단적 가치를 비교하였다.


결과: 최초 및 추적 MRI 검사에서 가장 민감도가 높은 sequence는 조영증강 T1-weighted imaging (이하 T1WI)였다 (각각 82%와 55.3%). 최초 MRI 검사에서 비조영 sequence 중에서 가장 민감도가 높은 것은 gradient-recalled echo (77.4%)였고 반면 fluid-attenuated inversion recovery (이하 FLAIR)는 낮은 민감도를 보였다 (34.4%). 추적 검사에서 FLAIR를 제외한 모든 sequence의 진단적 가치는 감소하였다. 추적 검사에서 FLAIR는 가장 민감도가 높았고 유일하게 34.4%에서 55.6%로 민감도가 상승한 sequence였다.

결론: 조영증강 T1WI는 최초 및 추적 MRI 검사에서 뇌정맥동혈전에 가장 높은 진단적 가치를 보였다. 그러나 뇌정맥동혈전의 추적 검사에 있어 조영증강 sequence는 합당하다고 할 수 있다. 그러나 MRI 조영제를 사용할 수 없는 환자의 경우에, 치료 효과 판정에 있어 FLAIR image에서 혈전의 신호 변화를 이해하는 것이 진단에 도움이 될 수 있을 것이다.

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