MRI diffusion-weighted imaging in intracranial hemorrhage (ICH)

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Abstract Purpose: To assess the role of MRI DWI in detection and characterization of ICH. Patients and methods: 61 patients with intracranial hemorrhage who underwent MRI (including DWI, ADC, and GRE) and CT were retrospectively included in this study. MRI DWIs were analyzed for age, type, (primary parenchymal hemorrhage or hemorrhagic lesion) and location of the hemorrhage. The results were compared with conventional MRI sequences, GRE, and CT to assess the diagnostic accuracy of DWI in assessment of patients with intracranial hematoma.

Results: We had 61 patients with intracranial hemorrhage, six cases were missed by DWI. MRI DWI was accurate for the detection of hyperacute, medium, large sized acute, early and late sub acute, subdural, hemorrhagic components of arterial and venous infarction, intraventricular hemorrage. DWI showed low sensitivity in detection of subarachnoid and small intraparenchymal hemorrhage The ADC measurements in hyperacute, acute, early and late subacute hematoma were statistically equivalent and were significantly less than the late subacute hematoma as well as the contralateral white matter.

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Conclusion: MRI DWI was accurate in detection, characterization and staging hyperacute, acute, subacute hemorrhage as well as hemorrhagic components of arterial and venous infarctions and of low diagnostic accuracy in subarachnoid and small parenchymal hemorrhage.

1. Introduction

Non contrast computed tomography (CT) has been the standard imaging modality for the initial evaluation of patients presenting with acute stroke symptoms (1,2). The primary diagnostic advantage of CT in the hyperacute phase (0–6 h) is its ability to rule out the presence of hemorrhage. Accurate early detection of blood is crucial since a history of intracerebral hemorrhage is a contraindication to the use of thrombolytic agents. However, a major disadvantage of conventional CT within the first few hours of symptom onset is its limited sensitivity for identifying early evidence of cerebral ischemia. Conversely, multimodal magnetic resonance imaging (MRI), including diffusion-weighted imaging (DWI), has excellent capacity to delineate the presence, size, location, and extent of hyperacute ischemia (3) but unproven reliability in identifying early parenchymal hemorrhage. The advent of thrombolytic therapy and other interventional therapies for acute ischemic stroke has led to increasing interest in using MRI to select and stratify candidates for treatments (4). Currently, many stroke centers obtain both CT and MRI in the initial evaluation of patients with stroke. The use of both modalities is time consuming and expensive (4).

2. Purpose

To assess the role of MRI diffusion weighted imaging in detection and characterization of intracranial hemorrhage.

3. Patients

Among all consecutive patients admitted to our institution between March 2008 and Feb. 2011, we retrospectively selected those who fulfilled the following criteria: (1) Intracranial hematoma unrelated to neoplasm; (2) patients performed MRI (including DWI and GRE) and CT with time interval between the CT and MRI examinations 2–4 h.

61 patients (10 females and 51 males; mean age, 56 years; range, 19–83) fulfilled these criteria and constituted our study group.

4. Imaging techniques

MR examination was done for all patients using Magnetom synergy, syngo, 1.5 T machine. The conventional MR imaging protocol included (a) axial T1-weighted spin-echo (467/9 [repetition time (TR) msec/echo time (TE) msec]), (b) axial T2-weighted fast spin-echo (3417/102 [effective echo time]), 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 5-mm/2-mm slice thickness/intersection gap. Singleshot, spin-echo, echo-planar DWI sequences were obtained by applying diffusion gradients in three orthogonal directions at each slice, with two diffusion weights (b value = 0 and 900 or 1000 s/mm²). Isotropic DWI was generated on-line by averaging three orthogonal-axis images. The DWI examination acquired 20 slices with parameters of 6500/96.8 (TR/TE), a 128 128 matrix, a 28-cm field of view, and 5-mm slice thickness with a 2-mm intersection gap. gradient-echo imaging (TR/TE = 450/20).

Computed tomographic scans were performed on Lightspeed scanner (General Electric). Images were acquired following the orbito-meatal plane with 3 mm thickness for the entire examination.

5. Imaging analysis

All the MRI and CT examination were reviewed by experienced neuroradiologist. Interpretations for each imaging
modality (CT and MRI) for a single patient were performed on different days to avoid reader recognition or recall of findings from the other modality. The order of presentation of the films was randomized and differed for each modality.

Diffusion weighted imaging was analyzed for
- Type of hemorrhage; parenchymal, intraventricular, subarachnoid, subdural, and epidural.
- Location of the hemorrhage; cortical, subcortical or basal ganglia.
- Age of the hemorrhage. According to the time interval between symptom onset and initial MRI, four stages were categorized: hyperacute, acute, early subacute and late subacute.

### 6. Quantitative analysis

It was used to determine the apparent diffusion coefficient (ADC) of each ICH (hyper acute, acute, early subacute and late subacute) at its center, as seen at DWI. A region of interest (ROI) was carefully placed within the hematoma and also in contralateral normal white matter. The ROI was drawn as large as possible while using a circular or rectangular ROI on the workstation, and its area ranged from 14 to 302 mm². ADC calculation could not be done in small areas of hemorrhage. In each case, the radiologist measured the ROI and the ADC values were calculated. All data concerning ADC values are presented as means ± standard deviation.

### 7. Statistical analysis

The presence of intracerebral hematomas was proved by CT, GRE and conventional MRI sequences

### 8. Results

- Table 1 showed the signal intensities of the different types of brain hemorrhage
- Hyperacute blood was found in three cases, all were detected by diffusion weighted imaging.
- Acute intracerebral hematoma was found in 11 cases, all were detected by diffusion weighted imaging.
- Small parenchymal hemorrhage (post traumatic) was found in four cases, three of them were missed by DWI (Table 2).
- Early subacute hematoma was found in seven cases, all were detected by diffusion weighted imaging.
- Late subacute hematoma was found in nine cases, all were detected by diffusion weighted imaging (Table 3).
- Subdural hematoma was found in five cases (1 early and 4 late subacute), all were detected by diffusion weighted imaging.
- Intraventricular hematoma was found in four cases, all were equally detected by diffusion weighted imaging.
- Hemorrhagic arterial infarction was found in eight cases, all were detected by DWI.
- Hemorrhagic venous infarction was found seven cases, one case was missed by DWI (Table 4).
- Subarachnoid hemorrhage was found in three cases, two of them were missed by DWI (Table 5).

The ADC measurements in hyperacute, acute, early and late subacute hematoma were statistically equivalent. The ADC measurements in hyperacute, acute, early and late subacute hematoma were significantly less than the late subacute hematoma as well as the contralateral white matter (Table 6).

### 9. Discussion

Neuroimaging plays a crucial role in the evaluation of patients presenting with acute stroke symptoms. While patient...
symptoms and clinical examinations may suggest the diagnosis, only brain imaging studies can confirm the diagnosis and differentiate hemorrhage from ischemia with high accuracy. This differentiation is critical in making acute treatment decisions, including patient eligibility for thrombolytic therapy (5,6).

In the current study we had 61 patients with intracranial hemorrhage, six cases were missed by DWI.

- In the current study all the three cases of hyperacute hematoma (Fig. 1), were detected by DWI showing heterogeneous hyperintense core, hypointense rim surrounded by perifocal brain edema. The central hyperintensity has been attributed to intracellular oxyhemoglobin and the hypointense rim to early intracellular deoxyhemoglobin at the periphery of a hematoma. This characteristic hypointense rim has been reported to occur within the first few hours of hemorrhage and in patients with acute neurologic symptoms is valuable for differentiating between acute ischemic stroke and hemorrhage (6,7). This hypointense rim was more obvious in GRE than in DWI in the current study (5,6).

  Fig. 1  A 53-year-old man with hyperacute intracerebral hematoma with images obtained 2 h after the onset of symptoms. Left frontotemporal hyperacute intracerebral hematoma with intraventricular extension appearing hyperdense in CT (a), isointense in T1WIs (b), heterogeneous hyperintense in T2WIs (c), heterogeneous hyperintense in DWI with peripheral hypointense rim (arrow in d), heterogeneous hypointense in ADC (e) and heterogeneous hyperintense in GRE (f). The peripheral hypointense rim is more obvious in GRE.

The signal intensity of hyperacute ICH observed at DWI was consistent with the findings of previous studies (8). The MR features of hyperintensity at the core of a hematoma and focal variable hypointensity were consistently found in all patients with hyperacute ICH. Hypointensity within a hyperacute hematoma, revealed by DWI, may be an important feature for differentiating hemorrhage from infarction in the practical clinical setting of hyperacute stroke. The focal hypointensity seen at DWI within a hyperacute hematoma may be caused by uncotted liquid separated from a retracted clot (9,10). Previous studies have suggested that the cause of hypointensity within a hyperacute hematoma, seen on DWI may be the early presence of paramagnetic deoxyhemoglobin (11,12). In all patients with hyperacute hematoma in the current study, T1-weighted imaging revealed a thin, slight hypointense rim. On T2-weighted images, this was iso- or hypointense and was located at the periphery of the hematoma, inside the region of perilesional hyperintensity, a finding consistent with edema in adjacent parenchyma. Compared with T2-weighted images, conventional gradient-echo images showed mixed iso- or hyperintensity at the center of the hemorrhage and a more noticeable hypointense rim at its periphery.

In the current study, all the 11 cases of acute hematoma (Figs. 2 and 7) and cases of early subacute hematoma were detected by DWI showing markedly hypointense core at DWI, T2-weighted images, FLAIR and GRE. This hypointensity has been attributed to the magnetic field inhomogeneity caused by paramagnetic intracellular deoxyhemoglobin in acute hematoma (13) and paramagnetic intracellular methemoglobin in early subacute hematoma (14). At both stages, DWI consistently revealed that in all these patients, a thin, markedly hyperintense rim, varying in thickness and completeness, was
present at the periphery of the hematoma. The bright rims corresponded to the areas of hyperintensity seen on T2-weighted images. In Echo-planar gradient-echo images the signal intensities observed were markedly hypointense, though the hyperintense rim seen at DWI was not demonstrated. T1-weighted images showed the hematoma as heterogeneously isointense at the acute stage and markedly hyperintense at the early subacute stage.

Small post traumatic parenchymal hemorrhage was found in four cases in our study, three cases of them were missed by DWI. All these cases were detected by CT showing small hyperdensity. These focal areas were hypointense by GRE (we could not confirm if these areas were acute or chronic hematoma) and missed by T1 and T2WIs. In addition, the four post traumatic patients in the current study, showing small areas of restriction on DWI seen in the splenium of corpus callosum not seen by CT and GRE (Fig. 3).

Physicians should be aware that in cases of small hemorrhages, it may be difficult to make an exact distinction between acute and chronic hemorrhage based on GRE images alone. A noncontrast CT may be necessary in these cases to determine hemorrhage age. With acute medium-large hemorrhages, the characteristic appearance of mixed signal intensity and the surrounding hyperintensity due to edema is very specific and will make the age of the hemorrhage apparent. However, small hemorrhages may have similar characteristics to calcifications and intravascular thrombus and have minimal edema making the determination of hemorrhage age as well as the distinction of hemorrhage versus nonhemorrhage more difficult (15,16).

Late subacute hematoma was found in 9 cases in the current study, all of these cases showed marked hyper intense core with hypo-intense rim (Fig. 4). All the cases also showed marked hyper intensity at T1- and T2-weighted, and FLAIR images while GRE demonstrated heterogeneous hyperintensity (16,17).

We had five cases of Subdural hematoma (1 early subacute and 4 late subacute), all showing heterogeneous signal at DWI. This may be explained by the fact that the subdural hematoma is almost always mixed (acute, early and late subacute), and the hypointensity is caused by paramagnetic intracellular deoxyhemoglobin and paramagnetic intracellular methemoglobin (17) (Fig. 5).

We had 4 cases of intraventricular hematoma (Fig. 1), all showing low signal at DWI.

We had 8 cases of hemorrhagic arterial and 7 cases of hemorrhagic venous infarction (Figs. 6 and 7) all showing low signal areas at DWI within the bright infarction.

In our study all the eight cases of hemorrhagic arterial and seven cases of hemorrhagic venous infarction (Figs. 6 and 8) appeared heterogenous on DWI showing areas of low signal intensity within areas of restricted diffusion. These findings were in agreement with previous studies (18,19) and was explained by the presence of prominent vasogenic edema associated with mild cytotoxic edema (20). The hemorrhagic areas in hemorrhagic arterial and venous infarctions gave the signal intensity of early subacute hematoma on DWI, T1WIs, and T2WIs.
The implication of this finding for the neuroimaging evaluation of acute stroke patients who are candidates for thrombolytic therapy is unclear. In the National Institute of Neurological Disorders and Stroke (NINDS) trial, intravenous tPA was shown to be effective based on CT enrollment criteria (19). While it may be hypothesized that patients with MRI evidence of hemorrhagic transformation are at higher risk of developing symptomatic hemorrhage if treated with thrombolytics, it is also possible that overall this group of patients may receive net benefit from therapy (19,21,22).

- We had three cases of subarachnoid hemorrhage in our study, only one case seen on DWI showed area of low signal intensity at the left temporal sulci surrounded by brain edema (Fig. 8). These findings were in agreement with previous studies (23,24,25).

Fig. 3 A 35-year-old man with post traumatic intracerebral hematoma with images obtained after 6 h. Left frontal small areas of hemorrhage appearing hyperdense in CT (b) (straight arrow) hyperintense in FLAIR (d), not seen in T1 and T2WIs, appearing hyperintense in DWI (j), hypointense in ADC (l) and GRE (n) interpreted as old hematoma. There is an area of diffusion restriction (contusion) in the splenium of corpus callosum only seen in DWI (i), ADC (k) (curved arrow) and FLAIR (c).
The ADC measurements in hyperacute, acute, early and late subacute hematoma were statistically equivalent. The ADC measurements in hyperacute, acute, early and late subacute hematoma were significantly less than the late subacute hematoma as well as the contralateral white matter (p value < .001).

The precise biophysical explanation for the observed restriction of diffusion in early stages of intracranial hematomas is uncertain. Potential causes include, but are not limited to: (1) a shrinkage of extracellular space with clot retraction; (2) a change in the osmotic environment once blood becomes extravascular, which...
alters the shape of the RBC, a phenomenon related to the formation of the fibrin network associated with clot; (3) a conformational change of the hemoglobin macromolecule within the RBC; and the less likely possibility of (4) contraction of intact RBCs (thereby decreasing intracellular space) (24,25).

Our study may have implications for the imaging evaluation of patients with acute stroke symptoms. Our findings support prior studies suggesting that MRI DWI is accurate in detection characterization and staging of hyperacute, medium and large sized acute, and early sub acute hemorrhage. One important caveat is that with small hemorrhages, blood that appears as acute on CT may appear as ischemic foci on DWI and as chronic hemorrhage on GRE MRI. A noncontrast CT may be required to confirm the diagnosis in these cases. However in cases of post traumatic axonal injury, small areas of contusion were detected by DWI in the corpus callosum in our study not detected by CT or GRE. Our study suggests that DWI and GRE MRI may be able to detect regions of hemorrhagic arterial and venous infarction not evident on CT. Our findings suggest that DWI was nearly as accurate as CT for the detection of early subacute hemorrhage and subdural hematoma. Our study confirms the superiority of DWI for detection of late subacute subdural. DWI was not accurate in detection of subarachnoid hemorrhage.

10. The limitations of this study

They include the lack of histopathological confirmation and the small number of cases. Although a complete understanding of the underlying biophysical basis may require further studies with a large population, our data suggest that the appearance of intracerebral hematomas on diffusion-weighted images is influenced not only by ADC values but also by magnetic susceptibility and T2 shine-through effects. In addition, our study corroborates the key features of evolving intracerebral hematomas, as depicted by conventional MR imaging.

11. Conclusion

Due to its advantages in delineating ischemic pathophysiology, MRI DWI was accurate in detection, characterization and staging hyperacute, subacute hemorrhage as well as hemorrhagic components of arterial and venous infarctions and of
low diagnostic accuracy in subarachnoid and small parenchymal hemorrhage.

References


Fig. 7 A 58 year old female with right occipital hemorrhagic venous infarct appearing hypodense in CT (a). The hemorrhagic area appears hyperintense in T1WIs (b), hypointense in T2 WIs (c), FLAIR (d), DWI (e), ADC (f), and GRE (g). There was marked attenuation of the superior sagittal sin in MRV (h).

Fig. 8 A 55 year old man with left sided subarachnoid hemorrhage seen by T1, FLAIR, T2WIs, DWI, ADC and GRE (a–f). It appears hyperintense in T1WIs, hypointense in T2WIs, FLAIR, DWI, ADC and GRE surrounded by brain edema.