Susceptibility–Diffusion Mismatch in Hyperacute Stroke: Correlation with Perfusion–Diffusion Mismatch and Clinical Outcome

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Background: A prominent vein (PV) on susceptibility-weighted imaging (SWI) was recently proposed to be a marker of the penumbra. We aimed to compare the utility of SWI and perfusion-weighted imaging (PWI) sequences for the evaluation of the penumbra in hyperacute middle cerebral artery (MCA) stroke, and to determine whether SWI–DWI mismatch is a neuroimaging marker of clinical outcome. *Methods:* A total of 149 consecutive patients with MCA stroke were prospectively enrolled. Magnetic resonance imaging (MRI) was performed within 6 hours of the onset of stroke. The ASPECTS values on diffusion-weighted imaging (DWI), PWI (delayed mean transit time), and SWI (visualization of PVs) were calculated by 2 independent raters. Correlation between PWI-ASPECTS and SWI-ASPECTS was calculated with the Pearson coefficient. Reliability of the PV rating system was calculated by an intraclass correlation coefficient (ICC). Favorable outcome was defined as a modified Rankin Scale score of 0-2 at 3 months for the 88 patients who received thrombolytic therapy. *Results:* The ASPECTS-SWI and ASPECTS-PWI scores showed a good correlation (Pearson coefficient of .69, $P < .001$). The reproducibility between the findings of the junior and the senior radiologists was excellent with an ICC of .89 (confidence interval of 95% (IC95): .85-.92, $P < .001$). However, neither SWI–DWI mismatch nor PWI-SWI mismatch was associated with clinical outcome. *Conclusion:* SWI and PWI were complementary but not commutable for the assessment of the penumbra. Susceptibility–diffusion mismatch was not found in this study to have predictive value for stroke outcome. **Key Words:** Susceptibility-weighted imaging—stroke—prominent veins—penumbra—Rankin scale.

Introduction

In acute stroke patients, the penumbra is defined as brain tissue with loss of electrical activity that retains the potential for recovery, provided that the occluded artery is recanalized in a timely manner.[1] In standard practice, the penumbra is estimated from the mismatch between signal abnormalities on perfusion-weighted imaging (PWI), which shows hypoperfused territories, and diffusion-weighted imaging (DWI), which is supposed to reflect the core of the infarct. Even if the optimal perfusion parameters are less debated, PWI may overestimate the extent of penumbral tissue[2] by including regions of benign oligemia.[3,4]

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Received October 25, 2015; revision received January 18, 2016; accepted February 19, 2016.

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1052-3057/$ - see front matter

http://dx.doi.org/10.1016/j.jstrokecerebrovasdis.2016.02.025

Studies published during the past 10 years have shown that a new sequence called susceptibility-weighted imaging (SWI) sequence is useful for the early evaluation of strokes.[5] SWI is a high-resolution, 3-dimensional, T2*-weighted gradient-echo magnetic resonance (MR) technique that is highly sensitive to paramagnetic substances, such as blood products, iron, and calcifications.[6]

SWI sometimes shows asymmetric prominent hypointense vessels in stroke patients resulting from differences in the concentration of deoxyhemoglobin between ischemic and normal brain areas.[7,8] Prominent veins (PVs) are thought to be caused by an increase in oxygen extraction fraction (OEF), which reflects the ratio of deoxyhemoglobin to oxyhemoglobin in the capillaries and veins.

SWI is considered a noninvasive MR blood oxygen level-dependent sequence that can be used for assessing the penumbral imaging in acute stroke.[9]

Magnetic susceptibility difference between deoxyhemoglobin and oxyhemoglobin provides a powerful endogenous MR contrast that is dependent on blood oxygenation level.

Following acute ischemic stroke, the OEF of the penumbra increases; OEF is considered as a surrogate of tissue viability and can be used to directly assess oxygen metabolism in ischemic tissue.[10]

SWI method does not provide measurements of brain oxygenation at the tissue level but, rather, signal or phase changes within veins close to the ischemic tissue. The PVs shown by SWI may delineate the penumbra region.[11,12]

Therefore, imaging tissue oxygen metabolism may provide a more direct assessment of tissue viability and may be a better tool to estimate penumbra than the PWI.[13]

The purpose of the present prospective study was to compare the utility of SWI and PWI sequences for the evaluation of penumbral tissue and to examine the association between susceptibility–diffusion mismatch and a favorable outcome.

Materials and Methods

Patients

Stroke patients treated in the stroke unit of Tours University Hospital were consecutively included over a 12-month period, between June 2012 and June 2013, if they had had an acute ischemic stroke and a 3-T brain magnetic resonance imaging (MRI) including readable SWI and T2*-weighted sequences performed within the first 6 hours after the onset of symptoms and before the administration of treatment. Acute ischemic stroke was defined as the sudden onset of clinical symptoms, and MRI findings of restricted diffusion confirmed on apparent diffusion coefficient images. All imaging and clinical data were generated during routine clinical workup. The protocol was approved by the human ethics committee of our hospital.

Imaging Protocol

MRI was performed with a 3-T MR system (Verio Tim; Siemens AG, Erlangen, Germany) using a 12-channel head coil. The following sequences were performed:

1) Axial T2*-weighted gradient-echo (25 slices, slice thickness: 5 mm, repetition time = 488 milliseconds, echo time = 10 milliseconds, flip angle: 15°, matrix 187 × 256 pixels, field of view [FOV]: 24 × 24 cm).
2) Axial fluid-attenuated inversion recovery (25 slices, slice thickness: 5 mm, interslice gap: 1.5 mm, repetition time = 9000 milliseconds, echo time = 123 milliseconds, inversion time = 2500 milliseconds, FOV = 25 × 25cm).
3) DWI was acquired using an isotropic single-shot echo-planar sequence with the following parameters: repetition time/echo time = 12,600/87 milliseconds, matrix 115 × 128 pixels, FOV = 24 cm, b = 1000 s/mm^2, slice thickness: 5 mm with an interslice gap of 1.5 mm. The apparent diffusion coefficient maps were calculated.
4) SWI: the magnitude and phase images were obtained with the following parameters: repetition time/echo time = 36/18 milliseconds, flip angle: 15°, matrix 192 × 256 pixels, FOV = 265 × 265 mm, slice thickness: 2 mm with an interslice gap of .4 mm, 88 slices, partial Fourier's plan acquisition of 6/8 images. Minimum-intensity projection post processing was performed with a slice thickness of 16 mm and an interslice gap of 2 mm with the post-treatment software of the manufacturer.
5) PWI data were acquired after an intravenous bolus injection of gadolinium (MultiHance, Bracco, Milan, Italy) and using the following parameters: repetition time/echo time = 1750/29 milliseconds, slice thickness: 4 mm with an interslice gap of 1 mm, 29 slices, and a matrix of 128 × 128 pixels. The dynamic image acquisition started 35-40 seconds before the contrast agent entered the brain and ended after a few recirculation passes of the contrast agent, with the first pass approximately in the middle of the acquisition. Mean transit time (MTT), relative cerebral blood flow and relative cerebral blood volume maps were then created by postprocessing the concentration–time curves for each pixel on a commercially available workstation (syngo.via, Siemens Healthcare, Forchheim, Germany).

Data Analysis

The following clinical variables were recorded: age, sex, National Institutes of Health Stroke Scale (NIHSS) score at admission, hemorrhagic transformation on the follow-up MRI for thrombolyzed patients, and modified Rankin Scale (mRS) score at 90 days.

Two radiologists (one with 1 year and another with 7 years of experience in stroke imaging) independently