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T₂*-sensitized High-resolution Magnetic Resonance Venography Using 3D-PRESTO Technique

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Purpose: We evaluated the ability of the PRESTO (principles of echo shifting with a train of observations) technique to reveal small veins and microbleeds in the human brain.

Materials and Methods: In an experimental study, we calculated contrast-to-noise ratio (CNR) between a cerebral parenchymal phantom and human venous blood using 3 sequences of 3-dimensional (3D)-PRESTO, 3D-gradient recalled echo (GRE), and 3D-GRE echo-planar imaging (EPI). Then, we examined 7 healthy volunteers and 5 patients with venous angiomas or traumatic brain injuries using the 3D-PRESTO technique. In volunteer studies, MR venographies were reconstructed from 10-mm, 15-mm, and 20-mm thickness data using the minimum-intensity-projection (MinIP) technique. Three radiologists identified deep brain venous anatomy and counted the visible left medullary veins. In clinical studies, we evaluated the lesion conspicuity of small venous diseases and microbleeds.

Results: In the phantom study, 3D-PRESTO showed the highest CNR. In all volunteer studies, the deep brain venous anatomy was readily identified in the MinIP images at each thickness. The mean numbers of counted left medullary veins were 5.1 for 10 mm, 5.9 for 15 mm, and 6.7 for 20 mm in the MinIP images. The difference was significant between 10-mm and 20-mm MinIP images ($P=0.02$). In patient studies, abnormal small veins and microbleeds were clearly revealed.

Conclusion: High-resolution MR venography using 3D-PRESTO technique can clearly depict small veins and microbleeds in the human brain.

Keywords: *BOLD, MR venography, PRESTO*

Introduction

Magnetic resonance (MR) venography is usually performed using time-of-flight or phase-contrast angiography techniques,¹ but these methods cannot identify small veins with slow flow. Recently, MR venography based on blood oxygenation level-dependent (BOLD) contrast has been developed in neuroimaging.^{2–4} The BOLD technique is based in the fact that paramagnetic deoxyhemoglobin causes localized magnetic field inhomogeneity, which produces both a reduction of T₂* and a phase difference between the venous vessel and its surrounding tissue.² Susceptibility-weighted imaging (SWI) is a new BOLD venography that uses both

magnitude and phase images from a high-resolution, 3-dimensional (3D), and fully velocity-compensated, gradient-echo sequence.^{3,4} SWI increases visibility of small veins and microbleeds because T₂* sensitivity to hemorrhage is also enhanced.

PRESTO (principles of echo shifting with a train of observations) technique is a unique sequence that combines elements of echo-shifted, gradient-recalled magnetic resonance (MR) imaging with the acquisition of multiple k-space lines within a single repetition time (TR) period. During this sequence, additional field gradients shift the refocused gradient echo into the subsequent TR period, which results in an echo time (TE) longer than the TR. This technique has been used exclusively for MR imaging studies like functional BOLD imaging or bolus tracking for perfusion investigations.^{5–8} Considering its properties as a fast T₂* sensitized se-

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quence, we speculated that 3D-PRESTO has the potential to be an alternative method to SWI.

Therefore, we undertook to assess the potential of the 3D-PRESTO for venography. Specifically, we compared the contrast-to-noise ratio (CNR) between PRESTO and conventional T_2^* sensitized sequences, optimized the thickness of minimum intensity projections (MinIP), and evaluated the ability of 3D-PRESTO to reveal small veins and microbleeds in the human brain.

Materials and Methods

All examinations were performed using a commercially available 1.5T MR system (Intera Master, Philips Medical Systems, Best, the Netherlands). Volunteer studies and clinical studies utilized a 6-channel head coil.

First, we scanned a cerebral parenchymal phantom made of polyvinyl alcohol (PVA) cryogel (MR imaging phantom 94-401, Nikko Fines Industries Co., Tokyo, Japan) and human venous blood in a transfusion pack. 3D-PRESTO, 3D-gradient recalled echo (GRE), and 3D-GRE-echo planar imaging (EPI) were applied to each phantom. The parameters for the imaging were: TR/TE = 24/40 ms for 3D-PRESTO, 68/40 ms for 3D-GRE, and 3D-GRE-EPI and field of vision (FOV) = 300 mm, flip angle = 20°, and matrix = 256 × 256 for all 3 sequences. The CNR between PVA cryogel and venous blood was calculated for each sequence by the following formula: $CNR = |SNR_A - SNR_B|$, where SNR_A = signal-to-noise ratio of PVA cryogel and SNR_B = signal-to-noise ratio of venous blood. SNR was calculated as $SNR = SI/SI_{BG}$, where SI = signal intensity of PVA cryogel or venous blood and SI_{BG} = background signal intensity.

Then, we examined 7 healthy volunteers (6 men, 1 woman; 27 to 37 years old, mean age, 30.4) and 5 patients (3 male, 2 female; 7 to 68 years old; 3 patients with venous angiomas, two with traumatic brain injuries). In volunteer studies, we obtained T_2^* -weighted gradient-echo images using the 3D-PRESTO technique: TR/TE = 40–46/50–56 ms, FOV = 250 mm, flip angle = 20°, and bandwidth per pixel in the read direction = 564 Hz. A total of 100 axial slices (slice thickness = 0.5 mm, noninterpolated acquisition matrix = 512 × 512) were acquired, resulting in an isotropic voxel size of 0.49 × 0.49 × 0.50 mm. Total scan time was 9 min. The datasets were transferred to a commercially available workstation (AZE Virtual Place, AZE, Tokyo), and MinIP axial images were reconstructed from 10-mm, 15-mm, and 20-mm thickness data. Three radiologists identified the deep brain venous anat-

omy (internal cerebral vein, direct lateral vein, anterior caudate vein, and septal vein) and counted the visible medullary veins in the left cerebral hemisphere at the slice level of the anterior caudate vein. The mean counted numbers of the medullary veins were compared for each MinIP image from different thickness data. Statistical analysis was performed using Fisher's PLSD, with $P < 0.05$ considered significant.

In the clinical studies, slice thickness was set to 0.75 mm (voxel size = 0.49 × 0.49 × 0.75 mm) and sensitivity-encoding with multiple receiver coils (SENSE) was utilized with a reduction factor of 1.8 to reduce scan time to 4 min for clinical use. We evaluated the visibility of the architecture of venous angiomas and microbleeds in traumatic brain injuries. Conventional contrast-enhanced, T_1 -weighted spin-echo image (TR/TE = 512/10 ms, slice thickness = 5 mm) in one patient with venous angioma and conventional T_2^* -weighted images (TR/TE = 1003/23 ms, flip angle = 25°, slice thickness = 5 mm) in 2 patients with traumatic brain injuries were scanned, and lesion conspicuity was compared between 3D-PRESTO and the conventional imaging methods.

Results

In the phantom study, 3D-PRESTO showed the highest CNR (13.5) compared to that of 3D-GRE (11.2) and 3D-GRE-EP (4.6).

In all the volunteer studies, the deep brain venous anatomy was readily identified in the MinIP images at each thickness. The mean numbers of counted left medullary veins were 5.1 from 10-mm thickness data, 5.9 from 15-mm data, and 6.7 from 20-mm data in the MinIP images. There was a significant difference in the mean number of counted left medullary veins between the 10-mm and 20-mm thickness MinIP images ($P = 0.02$) (Fig. 1a, b). The P value comparing 10-mm with 15-mm thickness MinIP images was 0.16 and comparing 15-mm with 20-mm thickness MinIP images was 0.18.

The method also worked well in clinical studies. In the 3 patients with venous angiomas, PRESTO images with MinIP clearly showed a caput medusae or an umbrella-like convergence of multiple venules on a single draining vein (Fig. 2). In the 2 patients with traumatic brain injuries, microbleeds could be identified as dark spots, and their margins were clearly delineated on each single slice (Fig. 3). Both venous angioma and microbleeds were more conspicuous in 3D-PRESTO than in conventional imaging methods (Figs. 2, 3).

Fig. 1. Magnetic resonance venography reconstructed from 10-mm (a) and 20-mm (b) thickness data of a 27-year-old healthy volunteer. The internal cerebral vein (black arrowhead), the anterior caudate vein (white arrow), and the septal vein (black arrow) can be clearly identified in both minimum-intensity-projection (MinIP) images. More medullary veins (white arrowhead) can be identified in the 20-mm MinIP images in one slice.

Fig. 2. A 61-year-old patient with a venous angioma. The 3-dimensional-PRESTO (principles of echo shifting with a train of observations) image reveals the caput medusae-like convergence of multiple venules and a draining vein (a). The converging venules are clearer in 3D-PRESTO than in the conventional contrast enhanced T₁-weighted spin-echo image (repetition time/echo time [TR/TE] = 512/10 ms) (b).

Discussion

SWI has been applied to clinical neuroimaging to diagnose small venous anomalies and microbleeds

barely visible with conventional imaging. SWI is reported useful in detecting and evaluating several brain diseases.⁹ For example, assessment of small veins allows detailed characterization of brain tu-

Fig. 3. A 7-year-old patient with traumatic brain injury. Microbleeds in the white and gray matter are shown as delineated dark spots (a). The lesions are more conspicuous in 3-dimensional-PRESTO (principles of echo shifting with a train of observations) than in conventional T_2^* weighted image (repetition time/echo time [TR/TE] = 1003/23 ms, flip angle = 25°) (b).

mors and vascular malformations, such as venous angiomas, cavernous hemangiomas, and arteriovenous malformations.¹⁰⁻¹² Depiction of microbleeds can provide useful information concerning tumor staging and the prospective clinical outcome of traumatic brain injuries or infarctions.^{10,13,14} In SWI, the phase mask is multiplied over the corresponding magnitude image, and by this post-processing procedure, the signal void in veins is enhanced, whereas the intensity in the parenchyma is left unchanged.^{2,3} Arteries are not shown on venography because they appear bright on the magnitude image and more or less isointense with the parenchyma on the phase-contrast image.

The PRESTO technique is a fast T_2^* -sensitized sequence that has been used for functional and perfusion studies,⁵⁻⁸ in which it was implemented as a 3D acquisition technique to optimize the signal-to-noise ratio, avoid inflow and slice-timing effects, and facilitate volume reconstruction. The spatial resolution was compromised to the voxel size of about $4 \times 4 \times 4$ mm because high temporal resolution was primarily required, and the whole brain needed to be covered in 1 to 2 s.⁵⁻⁸ However, high spatial resolution is crucial for MR venography to depict small cerebral veins.²

Our result showed 3D-PRESTO to have higher CNR between PVA cryogel and venous blood than did 3D-GRE and 3D-GRE-EPI, which suggests its potential for MR venography. For high-resolution

MR venography, we gave priority to spatial over temporal resolution and achieved an isotropic voxel size of $0.5 \times 0.5 \times 0.5$ mm. As a result, deep cerebral veins and medullary veins were revealed adequately in all volunteer studies. Moreover, when we used a voxel size of $0.5 \times 0.5 \times 0.75$ mm with SENSE, we could reduce the scan time to 4 min for clinical use.

The drawback of our method using the 3D-PRESTO technique was that the images comprised magnitude data, so arteries as well as veins appeared dark (Fig. 4). We speculate that this signal void in arteries is attributable to flow-dephasing phenomena. Therefore, in an area where veins and arteries run close, such as in the cortical area, both were seen on the image and could not be distinguished by signal intensity. This seems to be a disadvantage of 3D-PRESTO compared with SWI. However, this may not be a real clinical problem because with knowledge of vessel anatomy, we can easily identify the major arteries.

The 3D-PRESTO technique may be an alternative method to SWI, but further evaluation is required to confirm whether it can reveal the previously reported SWI findings in several brain diseases.

In conclusion, 3D-PRESTO has higher CNR than 3D-GRE and 3D-GRE-EPI. High-resolution MR venography using the 3D-PRESTO technique could clearly depict small veins in the human brain,

Fig. 4. Magnetic resonance venography reconstructed from 20-mm thickness data in the same volunteer as Fig. 1. The bilateral middle cerebral arteries (MCA) are shown as dark as veins (arrow-head). Though we cannot distinguish these arteries from veins by the signal intensity, we can identify MCA by their location and by pursuing the continuity with proximal major arteries, like the internal cerebral artery.

and more medullary veins are shown in 20-mm thickness MinIP images than in 10-mm and 15-mm thicknesses at one slice. Our preliminary clinical images could also depict venous angiomas and microbleeds.

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