Imaging of the intracranial venous system with a contrast-enhanced volumetric interpolated examination

Stephan G. Wetzel
Meng Law
Vivian S. Lee
Soonmee Cha
Glyn Johnson
Kim Nelson

Abstract A contrast-enhanced interpolated, three-dimensional (3D) gradient-echo MR sequence with asymmetric k-space sampling, which we refer to as volumetric interpolated brain examination (VIBE), was evaluated for its depiction of the normal intracranial venous system and compared with two-dimensional (2D) time-of-flight (TOF) MR venography (MRV). Fifteen subjects underwent contrast-enhanced VIBE imaging (TR/TE 8 ms/4.4 ms, flip angle 18°, acquisition time, 2 min 20 s, voxel size approximately 1.5 mm$^3$) and standard 2D TOF MRV (TR/TE 27 ms/9 ms, flip angle 35°). The presence of 19 venous structures per subject was assessed on maximum intensity projections (MIP) of the whole data set (whole-brain MIP) and on MIP images reconstructed spontaneously from source images (interactive MIP/source images). Results from a consensus reading where all imaging techniques and display modalities were available were taken as the standard of reference for the presence of venous structures. In addition, 10 subjects underwent both unenhanced and enhanced VIBE imaging. The value of subtracted data sets (unenhanced VIBE subtracted from enhanced VIBE) was then evaluated. Overall, VIBE provided a superior visualization of the cerebral veins than 2D TOF MRV (VIBE, sensitivity (reader 1/reader 2): 98%/99%, negative predictive value 64%/71%; TOF sensitivity: 85%/84%, negative predictive value 15%/15%; Wilcoxon signed-rank test VIBE vs TOF, p<0.001 for both readers). The VIBE interactive MIP/source images were superior to whole-brain MIP reconstructions. Image subtraction was not necessary for delineation of venous structures but improved small vein conspicuity. Contrast-enhanced VIBE acquisitions are faster and enable a visualization of the normal intracranial venous system superior to that of 2D TOF MRV.

Keywords Cerebral veins · Magnetic resonance angiography · Contrast media

Introduction

Most MRI techniques used to demonstrate the intracranial venous system rely on inflow enhancement – time-of-flight (TOF) [1] – or on phase changes induced in flowing blood by bipolar gradient pairs – phase contrast imaging [2]. However, both methods have several limitations:

1. Only the major cerebral veins and venous sinuses are reliably demonstrated.
2. Visualization of the cortical veins is usually inadequate.
3. Relatively long acquisition times are required.

With TOF MR venography (MRV) slow-flow or in-plane flow can lead to flow voids that are difficult to distin-
guish from venous sinus thrombosis [3]. Furthermore, the high signal intensity of substances with short T1-relaxation times, such as methemoglobin in a fresh thrombus, can be confused with flow-related enhancement on TOF MRV [4]. With phase-contrast imaging, inappropriate choice of velocity-encoding gradient can cause inadequate visualization of venous structures [5].

Three-dimensional (3D) contrast-enhanced MRV, performed with either conventional gradient-echo (GRE) sequences [6] or magnetization-prepared rapid acquisition GRE sequences (MP RAGE) [7], can provide good visualization of the normal venous system including the cortical veins. A recent study showed contrast-enhanced venography to be superior to 2D TOF MRV for the diagnosis of dural sinus thrombosis [8]; however, there are also limitations with contrast-enhanced venography. For example, a chronic venous thrombus may enhance as a result of vascularization or organization [8, 9] and hence an occluded part of the sinus might be mistaken as patent. In these cases application of unenhanced TOF MRV might be more appropriate [8]; however, in clinical practice the stage of a venous sinus thrombosis in a patient is often not known a priori. Given the nature of their limitations, flow-sensitive (TOF or phase-contrast) and contrast-enhanced MRV should be considered complementary methods for evaluating intracranial venous circulation. At present, measurement times of 6–12 min for contrast-enhanced MRV sequences are too time-consuming to be regularly used as an add-on examination to TOF or phase-contrast MRV for routine practice [5, 6, 7]. A rapid high-resolution contrast-enhanced MR sequence that could be acquired as an adjunct to TOF or phase contrast MRV would be clinically useful.

Rofsky et al. [10] recently described an interpolated 3D T1-weighted GRE sequence referred to as “volumetric interpolated breath-hold examination” (VIBE) for abdominal imaging that uses asymmetric k-space sampling and interpolation to shorten acquisition times. A modified version of this sequence can also be used to form rapid, high-resolution images of the brain, here termed “volumetric interpolated brain examination” [11]. This sequence has been shown to provide favorable signal characteristics compared with MP RAGE for parenchymal brain imaging. In this prospective study, we used a modified VIBE sequence to allow acquisition of a T1-weighted, fat-saturated, 3D data set of the whole brain with nearly isotropic voxels (1.5 mm$^3$) in approximately 2 min. We also sought to evaluate two additional aspects of VIBE MRV:

1. The utility of fast 3D reconstruction algorithms compared with conventional maximum intensity projections (MIP) for image interpretation
2. The effect of subtraction of unenhanced from enhanced VIBE MRV for the visibility of venous structures

We hypothesized that contrast-enhanced VIBE imaging would allow an improved visualization of the venous system compared with 2D TOF MRV in shorter acquisition times.

**Materials and methods**

**Study subjects**

For the main purpose of this study, 15 subjects underwent both contrast-enhanced VIBE imaging and 2D TOF MRV. A second subpopulation of 10 subjects underwent both unenhanced and contrast-enhanced VIBE imaging, with subsequent image subtraction to compare contrast-enhanced VIBE and subtracted VIBE. Five of these 10 subjects overlapped with the first group (those who underwent 2D TOF MRV as well) for a total of 20 subjects. All subjects (11 women, 9 men; average age 42.7±15.7 years, age range 18–69 years) were examined within a period of 3 months and underwent a clinically indicated contrast-enhanced MR examination of the brain. The clinical indications for imaging were as follows: postoperative follow-up after brain surgery (n=9), suspicion of or follow-up of metastatic disease or primary brain tumor (n=4), and suspicion of or follow-up of arterial vascular disease (n=7). Exclusion criteria were as follows: presence of large tumors causing significant mass effect or displacement of major cerebral veins, a history of venous sinus thrombosis, or severe claustrophobia or discomfort.

**MR imaging**

**MR equipment and MR protocols**

The MR imaging was performed on a 1.5-T system (Vision, Siemens Medical Systems, Iselin, N.J.) with maximum gradient strength of 25 mT/m and rise time of 600 µs using a quadrature head coil. The 2D TOF MRV sequence was performed prior to administration of contrast material. Contrast-enhanced VIBE was started approximately 1 min after intravenous injection of 20 ml gadopentetate dimeglumine (Magnevist, Berlex Laboratories, Wayne, N.J.), Subjects who underwent unenhanced and contrast-enhanced VIBE imaging were instructed not to move their heads during the acquisitions.

In all subjects the MR examination also included axial T1-weighted pre- and post-contrast spin-echo images, and axial T2-weighted turbo-spin-echo (TSE) images.

**MR sequences**

The VIBE sequence is a radio-frequency-spoiled 3D GRE sequence (TR/TE 8.8 ms/4.4 ms, flip angle 18°) that was acquired sagittally with a field of view of 220×192 (phase)×90 (partition). Sampling was symmetric in the read and phase-encoding direction giving in-plane voxel dimensions of 0.82×1.09 mm. In the partition direction, the center of k-space fell at line 21/90. Before Fourier transformation, the partition direction was zero-filled to 180 points for an interpolated voxel dimension of 0.89 mm in the partition direction. Zero filling is equivalent to interpolation and combined with asymmetric sampling gives improved spatial resolution [12]. As configured, resolution in the partition direction is between 0.89 mm (FOV of 160 mm/180 points after zero filling) and 1.78 mm (FOV of 160 mm/90 parti-