3D High-Spatial-Resolution Cerebral MR Venography at 3T: A Contrast-Dose-Reduction Study

BACKGROUND AND PURPOSE: The effect of various contrast-dose regimens for cerebral MR venography (MRV) has not been previously evaluated at 3T, to our knowledge. Our purpose was to evaluate and compare the diagnostic image quality resulting from half-versus-full-dose contrast regimens for high-spatial-resolution 3D cerebral MRV at 3T.

MATERIALS AND METHODS: Forty consecutive patients with known or suggested cerebrovascular disease underwent 3D high-spatial-resolution (0.7 × 0.6 × 0.9 mm³) cerebral contrast-enhanced MRV (CE-MRV) at 3T, by using an identical acquisition protocol. Patients were assigned to 1 of 2 groups: 1) full-dose (−0.1 mmol/kg), and 2) half-dose (−0.05 mmol/kg). Two readers evaluated the resulting images for overall image quality, venous structure definition, and arterial contamination. Signal intensity–to-noise-ratio (SNR) and contrast-to-noise-ratio (CNR) were evaluated in 8 consistent sites. Statistical analysis was performed by using Mann-Whitney U, Wilcoxon signed rank, and t tests and a k coefficient.

RESULTS: Both readers scored venous-structure definition as excellent or sufficient for diagnosis in approximately 90% of segments for the full-dose group (κ = 0.87) and in approximately 80% of segments for the half-dose group (κ = 0.85). Delineation grades were significantly lower for small venous segments, including the middle cerebral, septal, superior cerebellar, inferior vermian, posterior tonsillar, and thalamostriate veins in the half-dose group (P < .01). No significant difference existed for arterial contamination grades between the 2 groups (P > .05). SNR and CNR values were lower in the half-dose group (P < .01).

CONCLUSIONS: At 3T, high-spatial-resolution cerebral MRV can be performed with contrast doses as low as 7.5 mL, without compromising image quality as compared with full-dose protocols, except in the smallest veins, and without compromise of acquisition speed or spatial resolution.

Received June 25, 2008; accepted after revision August 11.

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DOI 10.3174/ajnr.A1319

AJNR Am J Neuroradiol 30:349–55 | Feb 2009 | www.ajnr.org 349
Materials and Methods

The institutional review board approved our Health Insurance Portability and Accountability Act–compliant study, and the requirement for informed consent was waived because the specific contrast dosage regimens tracked current institutional clinical practice.

Patients

Forty consecutive patients from a single institution, with known or suggested cerebrovascular disease, were evaluated with both 3D high-spatial-resolution CE-MR angiography (CE-MRA) and CE-MRV at 3T. Clinical indications included symptoms of transient ischemic attack (n = 9), vertigo/dizziness (n = 3), chronic headache (n = 7), known or suggested cerebral venous thrombosis (n = 18), and intracranial arteriovenous malformation (n = 3). Exclusion criteria included all standard contraindications to MR imaging (cardiac pacemaker, claustrophobia, contrast agent allergy, implanted metallic devices). Consecutive patients were sequentially assigned to 1 of 2 groups (A and B), each with 20 patients: group A (12 men, 8 women; mean age, 52.8 years ± 15.2; age range, 29–81 years) and group B (9 men, 11 women; mean age, 54.5 ± 17.3 years; age range, 27–79 years).

With identical image acquisition protocols, groups A and B received full-dose (15 mL) and half-dose (7.5 mL) gadopentetate dimeglumine (Magnevist; Berlex Laboratories, Wayne, NJ) respectively, during an antecubital vein for contrast agent injection. For image acquisition, 24 reference k-space lines for calibration in each phase-encoding direction. These settings allowed acquisition of 160 partitions over a 244 mm FOV with the k-space matrix of 374 × 512 and result- ing true voxel dimensions of 0.7 × 0.6 × 0.9 mm³ in 24 seconds. An asymmetric k-space sampling scheme (partial Fourier 75%) was applied in all 3 planes to minimize the TE and the acquisition time. CE-MRV protocol was a non-breath-hold acquisition.

Incrementally, we decreased the dosage of contrast agent (Magne-
SNR and contrast-to-noise ratio (CNR) were measured for the following venous segments: the superior sagittal sinus, inferior sagittal sinus, straight sinus, transverse sinus, sigmoid sinus, vein of Galen, internal cerebral vein, internal jugular vein, basilar vein of Rosenthal, septal vein, superior cerebellar vein, posterior tonsillar vein, inferior vermian vein, superior ophthalmic vein, thalamostriate vein, superior petrosal sinus, and the cavernous sinus.

### Statistical Analysis

The Mann-Whitney U test and the Wilcoxon signed rank test were used to evaluate the significance of the differences in overall image quality, venous visibility and sharpness, and arterial contamination scores between the 2 groups for each reader and between the readers, respectively. The SNR and CNR values for the 2 groups were analyzed by the Student t test. Interobserver agreement for the scores assigned for assessment of overall image quality and visibility and sharpness of venous segments between the 2 readers was determined by calculating the κ coefficient (poor agreement, κ = 0; slight agreement, κ = 0.01–0.2; fair agreement, κ = 0.21–0.4; moderate agreement, κ = 0.41–0.6; good agreement, κ = 0.61–0.8; and excellent agreement, κ = 0.81–1). For all statistical tests, a 2-sided P < .05 was used as the criterion of significance.

### Results

All examinations were completed successfully, and all contrast agent administrations were performed without complications.

### Overall Image Quality

Reader 1 graded the overall image quality as excellent in 18 and good in 2 patients in the full-dose group. Reader 2 graded the overall image quality as excellent in 19 and good in 1 patient in the full-dose group (median, 3; range, 2–3) (κ = 0.64; 95% confidence interval [CI], 0.58–0.70). In the half-dose group, reader 1 graded the overall image quality as excellent in 16 and good in 4 patients. In the half-dose group, reader 2 graded the overall image quality as excellent in 18 and good in 2 patients (median, 3; range, 2–3) (κ = 0.62; 95% CI, 0.57–0.67). There was no significant difference for overall image quality scores between the 2 dose groups for each reader (P > .05) or between the readers (P > .05) (Fig 1). Parallel acquisition reconstruction artifacts were not noted, and image noise was not found to interfere with diagnostic image quality in any case.

### Evaluation of Venous Structure Definition on Full- and Half-Dose CE-MRV

In the full-dose group, of 640 venous segments for possible evaluation, 98.8% (632/640) of segments were visualized by both readers. Reader 1 identified 90.3% (578/640) of segments with grades for definition in the diagnostic range (grades 3 and 4) and 97.9% (62/640) of segments with insufficient definition for diagnosis (grades 1 and 2). Reader 2 identified 90% (580/640) of segments with grades for definition in the diagnostic range (grades 3 and 4) and 10% (64/640) of segments with insufficient definition for diagnosis (grades 1 and 2). There was no statistically significant difference in venous visibility and sharpness grades assigned by the 2 readers (P > .05 for all segments). The overall interobserver agreement for the as-
signed delineation grades was excellent (κ = 0.87; 95% CI, 0.83–0.91).

In the half-dose group (Figs 2 and 3), of 640 venous segments for possible evaluation, 95% (608/640) of segments were visualized by both readers. Reader 1 identified 80% (512/640) of segments with grades for definition in the diagnostic range (grades 3 and 4) and 20% (128/640) of segments with insufficient definition for diagnosis (grades 1 and 2). Reader 2 identified 80.9% (518/640) of segments with grades for definition in the diagnostic range (grades 3 and 4) and 19.1% (122/640) of segments with insufficient definition for diagnosis (grades 1 and 2). There was no statistically significant interreader difference in venous visibility and sharpness grades assigned (P > .05 for all segments). The overall interobserver agreement for the assigned delineation grades was excellent (κ = 0.85; 95% CI, 0.81–0.89).

Comparison of venous delineation grades assigned by each reader between the 2 groups by using the Mann-Whitney U test demonstrated significantly lower grades for small venous segments, including the middle cerebral, septal, superior cerebellar, inferior vermian, posterior tonsillar, and thalamostriate veins in the half-dose group as compared with the single-dose group (P < .01 for all). No statistically significant difference existed for the delineation grades assigned to the other venous segments (P > .05 for all) (Table 1).

**Evaluation of Contaminating Arterial Enhancement on Full- and Half-Dose CE-MRV**

For visualized segments, in the full-dose group, reader 1 graded contaminating arterial enhancement as none in 98.6% (623/632), minimal in 1.1% (7/632) (cavernous sinus, n = 7), and moderate in 0.3% (2/632) (cavernous sinus, n = 2) of venous segments. Likewise, reader 2 graded contaminating arterial enhancement as none in 98.4% (622/632), minimal in 1.3% (8/632) (cavernous sinus, n = 8), and moderate in 0.3% (2/632) (cavernous sinus, n = 2) of venous segments.

For the half-dose group, reader 1 graded contaminating arterial enhancement as none in 98.7% (600/608), minimal in 1.1% (7/608) (cavernous sinus, n = 7), and moderate in 0.2% (1/608) (cavernous sinus, n = 2) of venous segments. Like-
wise, reader 2 graded contaminating arterial enhancement as none in 99% (602/608), minimal in 0.8% (5/608) (cavernous sinus, n/H11005 5), and moderate in 0.2% (1/608) (cavernous sinus, n/H11005 2) of venous segments.

No statistically significant difference existed in arterial contamination grades assigned by each reader between the 2 groups (P/H11022 .05 for both readers).

Details of SNR and CNR values for venous segments are given in Table 2. Statistical analysis revealed significantly lower SNR (P < .01) and CNR (P < .01) values for evaluated venous segments in the half-dose group compared with the full-dose group. However, these differences on the images were not subjectively apparent to the reviewers.

Additional findings on the full-dose CE-MRV included arachnoid granulation (superior sagittal sinus, n = 3; transverse sinus, n = 2; sigmoid sinus, n = 2), transverse sinus thrombosis (n = 6), hypoplastic transverse sinus (n = 3), and arteriovenous malformation (n = 1). In the half-dose group, findings included arachnoid granulation (superior sagittal sinus, n = 4; transverse sinus, n = 2; sigmoid sinus, n = 2), hypoplastic transverse sinus (n = 1), transverse sinus thrombosis (n = 7), superior sagittal sinus occlusion (n = 1), and arteriovenous malformation (n = 2). The findings were confidently evaluated by both readers.

**Discussion**

The results of our study indicate that at 3T, high-spatial-resolution cerebral CE-MRV can be performed with a fraction of the contrast dose commonly used in routine practice, without compromise in pulse sequence performance or image quality for evaluation of major extra- and intracranial venous structures. We did observe that the visibility and sharpness of very
small intracranial venous segments were significantly lower in the half-dose CE-MRV group compared with the full-dose group. Because very small veins are uncommonly involved in symptomatic disease in the absence of concomitant larger dural sinus involvement, we believe this difference is not likely to be relevant in routine clinical practice.

Cerebral CE-MRV at 3T has emerged as a powerful noninvasive diagnostic tool for evaluation of intracranial venous structures. However, in the past there has been little emphasis on gadolinium contrast-dose minimization strategies. In this context, we sought to determine whether preservation of image quality could be achieved by decreasing the contrast dose without significantly sacrificing image quality.

At 3T, sequence performance is generally higher compared with lower field strength due to the higher available baseline SNR, which is used to increase speed, coverage, and/or spatial resolution by the use of parallel acquisition schemes. Because SNR is inversely related to spatial resolution, 1 approach to compensate for decreased contrast dose is to compromise on spatial resolution. However, for confident assessment of intracranial venous systems, a premium is placed on image quality and spatial resolution.

Successful application of CE-MR protocols with sufficient spatial resolution is related to the vascular SNR. Besides magnetic field strength and contrast agent relaxivity, SNR is directly proportional to the square root of TR/T1 and is inversely related to the square root of the acceleration factor and the coil geometry factor.

We agree with others that by raising the baseline signal intensity with stronger magnetic fields, using contrast agents with high relaxivity, reducing noise amplification by using receiver coils with more channels, and achieving optimized geometry and high-sensitivity profiles, the SNR level can be preserved. In addition, parallel acquisition–associated SNR penalty is mitigated at 3T.

In our study, the measured SNR and CNR values in the evaluated venous segments were significantly lower with the half-dose protocol compared with the full-dose protocol. However, the SNR and CNR were still adequate for confident evaluation of these segments, and there was no significant difference in the delineation grades of most venous segments between the 2 groups. Nevertheless, the visibility and sharpness of very small intracranial venous segments, including the middle cerebral, septal, superior cerebellar, inferior vermian, posterior tonsillar, and thalamostriate veins were significantly lower with the half-dose protocol. This may be attributed to the fact that sufficient SNR and CNR values were not achieved for these segments. Our results suggest that with our specific commercially available hardware configuration, there is little advantage to using higher contrast-dose protocols for assessment of major intracranial venous structures, which are the chief focus of clinically important questions. It is the high spatial resolution of the CE-MRV technique that is critical for visualization of venous segments and detection of venous abnormalities.

Previous studies have successfully implemented CE-MRV protocols for imaging of intracranial venous structures with the use of a single dose or higher doses of GBCA. Farb et al implemented a 3D GRE sequence with elliptic centric ordering achieving voxel dimensions of 0.78 × 0.78 × 1.3 mm³ at 1.5T. The investigators injected a fixed dose of 30 mL of contrast medium, and complete visibility was gained for 92% of segments.

Hu et al performed cerebral MRV at 1.5T, with a fourfold acceleration using a fast spoiled GRE sequence generating voxel dimensions of 0.8 × 0.8 × 1.4 mm³ in 65 seconds while injecting a fixed dose of 19 mL. Excellent overall diagnostic image quality was gained in 80% of patients. Nael et al implemented a 3D fast GRE sequence at 3T with an acceleration factor of 6 during injection of 0.15 mmol/kg of contrast agent (voxel dimensions 0.7 × 0.7 × 0.8 mm³), and diagnostic image quality was achieved in 90% of cerebral venous segments.

Our study at 3T indicates that despite using a fast high-spatial-resolution acquisition, image quality is comparable between full-dose and half-dose gadolinium infusion protocols for major intracranial venous segments.

Our study has some limitations. The 2 contrast agent–dose protocols evaluated were not applied to each individual. Therefore, comparison of the intravascular diagnostic image quality was not possible. Second, we did not undertake a comparison of the diagnostic sensitivity and specificity of this technique because doing so would require comparison with the gold standard, digital subtraction angiography (DSA), which was not realistic in such a large patient cohort. We believe further studies are warranted for additional assessment of diagnostic sensitivity and specificity of half-dose CE-MRV in correlation with DSA. Moreover, many of the patients in our study had no or low suggestion of cerebral venous disease. However, because the purpose of the study was to show the technical feasibility of the described half-dose protocol, the significance of this limitation was mitigated. Some of the venous structures, which were not visualized in this study, were possibly absent (normal variation), thus artifically decreasing our venous structure visualization rates. However, this could not be verified due to the lack of a gold standard.

Conclusions

Our study shows that by exploiting the higher SNR available at 3T in combination with multichannel coils and by effectively using highly accelerated parallel imaging, high-spatial-resolution cerebral CE-MRV at 3T can be performed with a gadolinium dose as low as 7.5 mL, without compromising image quality as compared with the full-dose protocol (15 mL). The clinical accuracy of this technique needs to be investigated in a broader clinical setting in a population of patients with cerebral venous disease.

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