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M. Lettau, K. Sartor, S. Heiland and S. Hähnel

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3T High-Spatial-Resolution Contrast-Enhanced MR Angiography of the Intracranial Venous System with Parallel Imaging

TECHNICAL NOTE

M. Lettau
K. Sartor
S. Heiland
S. Hähnel

SUMMARY: The diagnostic image quality of contrast-enhanced (CE) 3D MR venography (MRV) was prospectively compared with that of 2D time-of-flight (TOF) MRV and contrast-enhanced 3D magnetization-prepared rapid acquisition of gradient echo (MPRAGE) sequences for the visualization of the intracranial venous system at 3T in 22 patients. CE MRV provides high-quality images and was shown to be superior to TOF MRV and MPRAGE sequences in visualizing the normal intracranial venous system.

Contrast-enhanced (CE) MR venography (MRV) with 1.5T MR imaging has proved to be superior to time-of-flight (TOF)¹⁻³ as well as phase-contrast¹ MRV to visualize the intracranial venous system. Because small intracranial vein thrombosis is often associated with venous infarction or hemorrhage, MRV requires spatial resolution in submillimeter dimension. CE MRV with parallel imaging has been performed for imaging of the intracranial venous system with 1.5T MR imaging⁴ and 3T MR imaging.⁵ The magnetization-prepared rapid acquisition of gradient echo (MPRAGE) sequences have already been implemented to visualize the intracranial venous system with 1.5T MR imaging.^{6,7} The goal of our study was to compare CE MRV, TOF MRV, and MPRAGE sequences using 3T MR imaging with parallel imaging for the visualization of the intracranial venous system.

Technique

Patients

From October 2006 through February 2007, a total of 22 consecutive patients (8 men, 14 women; mean age, 42.4 years; age range, 17–70 years) were examined prospectively. There was a broad spectrum of clinical indications. In 12 patients, cerebral venous thrombosis was suspected. Our study was approved by the responsible ethics commission.

MR Examinations

We performed all MR imaging studies using a 3T system (Trio; Siemens Medical Systems, Erlangen, Germany) with an 8-element head coil. After routine MR imaging, we performed the following protocol: TOF MRV, nonenhanced MPRAGE sequence, bolus-detection sequence, and nonenhanced CE MRV acquisition. Also, after a single injection of contrast medium, a contrast-enhanced CE MRV acquisition and a contrast-enhanced MPRAGE sequence were performed. The imaging parameters are listed in Table 1. As contrast agent, gadopentetate dimeglumine (Magnevist; Bayer Schering Pharma, Berlin, Germany) at a dose of 0.1 mmol/kg was injected intravenously at a rate of 3 mL/s with use of an injector.

Table 1. Imaging parameters in CE MRV, TOF MRV, and MPRAGE sequences

Parameter	CE	TOF	MPRAGE
Sequence	3D FLASH	2D TOF	3D MPRAGE
Orientation	Sagittal	Coronal	Axial
TR (ms)	3.78	28	2250
TE (ms)	1.5	6.93	3.04
Inversion time (ms)			900
Flip angle (°)	15	60	9
Bandwidth (Hz/pixel)	430	65	200
Section thickness (mm)	0.4	2.5	1.2
Sections/partitions	416	128	144
Distant factor (%)		–33	
FOV (mm)	(270–290) ²	220 × 220	220 × 220
Matrix	384 × 384	256 × 256	384 × 384
GRAPPA-factor	2	2	2
Acquisition time (min. sec)	1.15	5.14	5.35

Note:—CE indicates contrast-enhanced MR venography; FLASH, fast low-angle shot; TOF, time-of-flight MR venography; MPRAGE, magnetization-prepared rapid acquisition of gradient echo; GRAPPA, generalized autocalibrating partially parallel acquisition.

Image Analysis

The source images, subtraction images, 2D multiplanar reconstructed (MPR) images as well as 3D maximum intensity projection (MIP) angiograms were interpreted prospectively by 2 experienced neuro-radiologists. The image quality of 34 predefined venous structures was graded as follows: intense and continuous = 3, faint and continuous = 2, noncontinuous = 1, and invisible = 0. The grades assigned were the result of a consensus among the observers. In addition, the number of bridging veins seen on coronal images (Fig 1) was compared.

Statistical Analysis

We analyzed the differences in the number of bridging veins using the Wilcoxon matched-pairs signed-rank test. The nonparametric sign test was used to analyze differences in the image quality of the cerebral veins and dural sinuses. A commercially available statistical software package (SPSS 14.0; SPSS, Chicago, Ill) was used.

Results

We found significantly higher image quality scores on the CE MRV compared with the TOF MRV or MPRAGE sequences and on the MPRAGE sequences compared with the TOF MRV (Table 2 and 3). The number of detected bridging veins was significantly higher with the CE MRV compared with the TOF MRV or MPRAGE sequences (Table 3). In all of the 22 patients, MR imaging results did not show signs of cerebral venous thrombosis.

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From the Division of Neuroradiology, Department of Neurology, University of Heidelberg Medical Center, Heidelberg, Germany.

Please address correspondence to Michael Lettau, MD, Division of Neuroradiology, Department of Neurology, University of Heidelberg Medical Center, Im Neuenheimer Feld 400, 69120 Heidelberg, Germany; e-mail: michael_lettau@gmx.de

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Table 2. Comparison ($P < .05$) of the image quality of unpaired cerebral sinuses and veins in TOF MRV, CE MRV, and MPAGE sequences

Venous structure	Mean scores	CE/TOF	CE/MPAGE	MPAGE/TOF
	CE/TOF/MPAGE	Superior	Superior	Superior
Superior sagittal sinus	3.0/2.9/2.0	None	CE	TOF
Inferior sagittal sinus	2.3/1.6/2.0	CE	CE	None
Vein of Galen	3.0/2.6/3.0	CE	None	MPAGE
Straight sinus	3.0/3.0/2.7	None	CE	TOF
Intercavernous sinus	2.6/0.4/2.1	CE	CE	MPAGE
Basilar plexus	0/0/0	None	None	None

Note:—CE indicates contrast-enhanced MR venography; TOF, time-of-flight MR venography; MPAGE, magnetization-prepared rapid acquisition of gradient echo.

Discussion

Visualization of the normal intracranial venous system at 3T was superior on the CE MRV compared with the TOF MRV and MPAGE sequences. A crucial aspect of MRV is spatial resolution. In contrast to the results of Kirchhof et al,¹ who used imaging at 1.5T, in our study, in which imaging at 3T with a higher spatial resolution of CE MRV was used, most of the defined different venous structures were visualized more effectively by CE MRV compared with TOF MRV. The section thickness of CE MRV in our study is lower than previously reported in other studies with use of 1.5T¹⁻⁴ or 3T⁵ imaging. Another crucial aspect of CE MRV is the synchronization of the acquisition with the arrival of the contrast agent. Parallel imaging techniques increase the time efficiency of spatial signal intensity encoding but are generally associated with a reduction in the signal-to-noise ratio. Hu et al⁴ demonstrated that, at 1.5T, CE MRV accelerated by 4 with a shorter acquisition time was superior to an unaccelerated counterpart. Nael et al⁵ reported a CE MRV accelerated by 6 on a 32-channel 3T MR imaging system. We used a CE MRV accelerated by 2 on an 8-channel system for comparison with twofold accelerated TOF MRV and MPAGE sequences.

Well-known disadvantages of TOF MRV are signal intensity loss because of in-plane saturation effect as well as the slow and turbulent flow. In our study, the transverse and sigmoid

sinuses were visualized best by CE MRV. As with Ayanzen et al,⁸ we observed flow gaps in the transverse sinuses with TOF MRV in several patients (Fig 2). In isolated cortical vein thrombosis, the diagnosis can be extremely difficult. In our study, the superficial veins were visualized best by CE MRV (Fig 3).

At 1.5T, Liang et al⁷ showed MPAGE sequences to be superior to TOF MRV. In our study, disadvantages of the MPAGE sequences were a signal intensity loss at the upper and lower end of the head coil in every patient and dural contrast enhancement, as some venous structures could not easily be distinguished from dural enhancement (Fig 1).

Our study had the following limitations: There was low statistical impact because of a small number of patients. Furthermore, cerebral venous thrombosis could not be detected in any of the participants; thus, the drawing of conclusions from these data about the performance of CE MRV and MPAGE sequences in the detection of venous thrombosis remains difficult. Technical disadvantages, such as a relatively long TE on TOF MRV sequences, anisotropic voxels, and low acceleration factors at parallel imaging were limitations to this study. Furthermore, the performance of contrast-enhanced CE MR acquisition before contrast-enhanced MPAGE sequence in all patients was considered a possible disadvantage.

Table 3. Comparison ($P < .05$) of the image quality of paired sinuses and veins and bridging veins in TOF MRV, CE MRV, and MPAGE sequences

Venous structure	Mean scores/number	CE/TOF	CE/MPAGE	MPAGE/TOF
	CE/TOF/MPAGE	Superior	Superior	Superior
Transverse sinuses	R:3.0/2.6/3.0 L:3.0/2.2/3.0	CE	None	MPAGE
Sigmoid sinus R	3.0/2.4/2.0	CE	CE	TOF
Sigmoid sinus L	3.0/2.1/2.0	CE	CE	None
Jugular bulbs	R:3.0/2.2/2.0 L:3.0/2.1/2.0	CE	CE	None
Septal veins R	2.0/1.6/1.8	CE	CE	None
Septal veins L	2.0/1.6/1.9	CE	None	MPAGE
Thalamostriate veins	R:2.0/1.7/2.0 L:2.0/1.6/2.0	CE	None	MPAGE
Internal cerebral veins	R:3.0/3.0/3.0 L:3.0/3.0/3.0	None	None	None
Cavernous sinuses	R:2.2/1.0/2.0 L:2.2/1.0/2.0	CE	CE	MPAGE
Sphenoparietal sinuses	R:2.5/0.6/2.1 L:2.3/0.7/2.0	CE	CE	MPAGE
Superior petrosal sinuses	R:1.5/0.6/1.5 L:1.8/0.7/1.6	CE	None	MPAGE
Inferior petrosal sinuses	R:2.6/1.2/2.0 L:2.3/0.8/2.0	CE	CE	MPAGE
Basal veins of Rosenthal	R:3.0/2.3/2.9 L:3.0/2.6/2.9	CE	None	MPAGE
Trolard veins	R:2.3/1.0/1.7 L:2.5/1.1/1.8	CE	CE	MPAGE
Labbé vein R	3.0/2.1/2.6	CE	CE	MPAGE
Labbé vein L	3.0/2.4/3.0	CE	None	MPAGE
Sup. middle cerebral vein	R:2.9/1.8/2.3 L:2.8/1.5/2.3	CE	CE	MPAGE
Bridging veins	R:8.8/3.6/4.9 L:7.9/3.3/4.4	CE	CE	MPAGE

Note:—CE indicates contrast-enhanced MR venography; TOF, time-of-flight MR venography; MPAGE, magnetization-prepared rapid acquisition of gradient echo; R, right; L, left; Sup, superior.

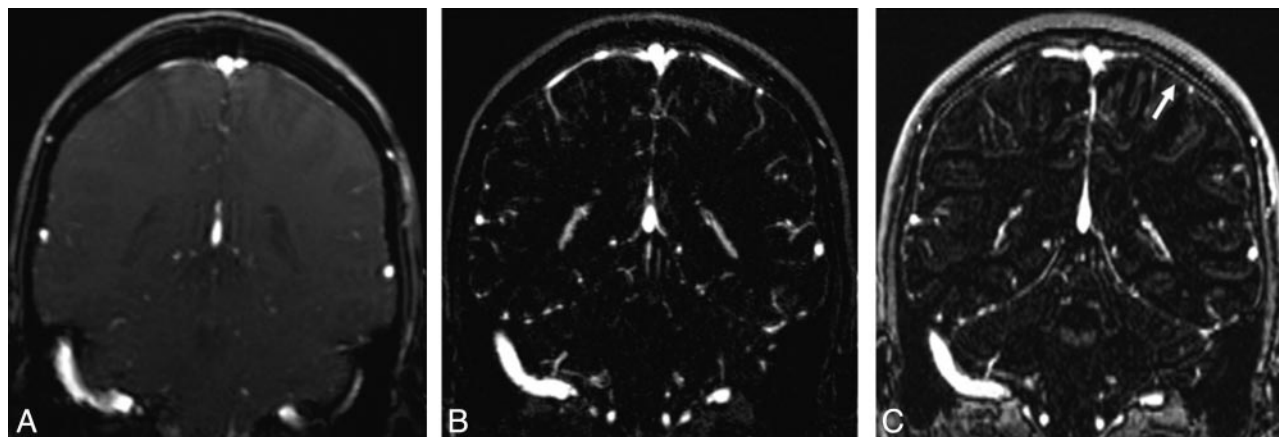


Fig 1. Coronal 2D MPR images obtained from 2D TOF MRV (A), CE MRV (B), and MPRAGE sequences (C). The section thickness is 2.5 mm (A), 0.7 mm (B), and 1.2 mm (C). The number of bridging veins in both hemispheres was compared. On the MPRAGE sequences (C), the bridging veins could not easily be distinguished from dural enhancement (arrow).



Fig 2. 3D MIP images obtained from 2D TOF MRV (A), and CE MRV (B). Note the flow gap in the left transverse sinus on 2D TOF MRV (A) and the intense and continuous signal intensity on CE MRV (B) images (arrows).

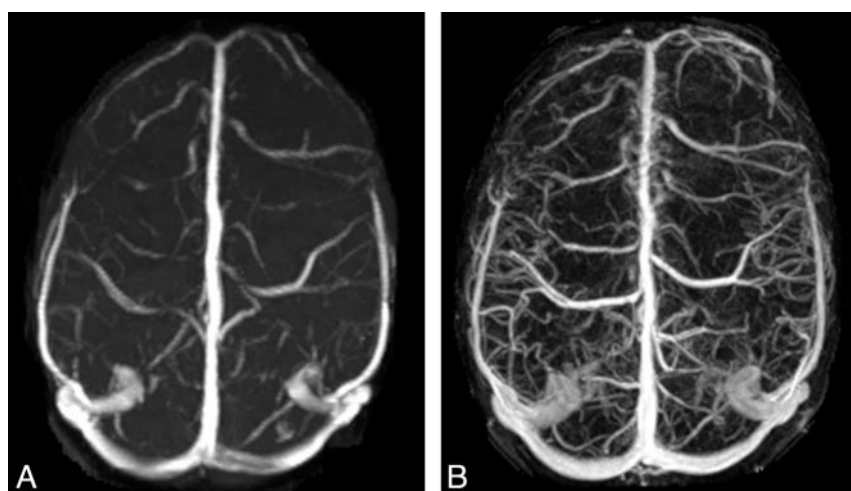


Fig 3. 3D MIP images obtained from 2D TOF MRV (A), and CE MRV (B). The superficial veins were detected best by CE MRV (B).

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