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Fast contrast-enhanced MR whole-brain venography

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Abstract Our aim was to assess the value of a new fast contrast-enhanced MR venography (CE-MRV) sequence in the investigation of normal and diseased cerebral veins. Conventional time-of-flight (TOF) MRV is time consuming, with imaging for a single sequence taking many minutes. MRI was performed with a clinical 1.5-T scanner; conventional TOF MRV followed by CE-MRV was performed using a modified 3D first-pass MR angiography sequence. Ten control subjects without cerebral pathology were studied as well as ten patients with cerebral venous thrombosis for a total of 20 studies with both sequences. CE-MRV was able to provide a set of complete MRV images in a significantly shorter time than conventional MRV sequencing could. The field of view also provided greater coverage of the vessels of the head and neck. CE-MRV also provided more extensive small vein detail and provided a better demonstration of intraluminal defects, despite a slightly lower resolution. Both methods were equally suited for the demonstration of venous thrombosis and demonstrated all cases equally well; however, CE-MRV provided more detailed information by showing partially obstructed sinuses and by showing better the presence of cortical collateral venous drainage.

Keywords Cerebral veins · Magnetic resonance angiography · Venography

Introduction

Originally thought to be a rare and deadly disease, cerebral venous thrombosis has been demonstrated to be more common than originally thought and also not necessarily associated with a bad prognosis. However, from both clinical and radiological standpoints its first signs and symptoms can be misleading [1, 2, 3], and it is not often easy to differentiate such diseases from those of arterial origin. Clinically, the patients usually present with headaches, seizures or other unspecific symptoms [4], therefore, it is very often important to include imaging of the cerebral veins in any imaging work-up in patients with acute neurological deficits. Since the underlying pathophysiology is one of vascular outflow obstruction and not of diminished flow, the resulting secondary changes are different from those found in arterial ischaemic stroke [5]. While anticoagulation with heparin is the standard treatment in most cases [6], direct interventional therapies have been tried in selected series [7, 8]. The gold-standard method for the demonstration of cerebral vasculature remains catheter angiography, which is invasive by nature and therefore unsuitable as a screening method. Computed tomography can

demonstrate unenhanced hyperdense vessels as well as areas of diminished enhancement on post-contrast images [9, 10]. MRI, due to its sensitivity to blood flow, cannot only demonstrate secondary parenchymal changes due to venous obstruction and stasis but can also provide diagnostic criteria by demonstrating the absence of flow voids on spin-echo images [11, 12]: static blood usually produces higher signal in the affected vessel on both T1- and T2-weighted spin-echo images. However, there is the possibility of flow-related spontaneous hyperintensity in the sinuses making imaging at times difficult to interpret. Gradient-echo imaging has also been one method to demonstrate sinus occlusion [13]. Also, MRI allows the demonstration of occlusion directly on MR angiography (MRA) or MRV sequences [14, 15, 16]. Most MRA methods use either phase-sensitive or time-of-flight techniques. When TOF imaging is used, which is time consuming, regions of slow or turbulent flow might cause attenuated vascular signal, leading to misinterpretation of results; also, the presence of blood breakdown products in the thrombus itself can create a high signal, mimicking flow [17, 18]. Phase-sensitive techniques have been shown to be able to demonstrate well slow or diminished flow such as is seen in sinus thrombosis [19] Computed tomography (CT) [20] and MRV techniques have recently been refined, which allows better vascular definition. Recent developments in contrast-enhanced 3D MRA sequences (3D CE-MRA) of the head and neck have been shown to be highly accurate for the diagnosis of carotid stenosis and occlusion [21]. These sequences are rapid and allow a better filling of the vessels, thereby providing a better definition of the vascular lumen. We wanted to investigate the use of a modified 3D CE MRA, sequence [(called contrast-enhanced MR venography (CE-MRV)] in the examination of cerebral veins, normal and diseased.

Subjects and methods

The study was performed over a period of 36 months between 1996 and 1999. and was fully in accordance with the ethical guidelines of our institution. All patients and controls were fully informed about the procedure and its potential disadvantages. They all gave signed, informed consent concerning the MRI procedure. At first, 32 control subjects without signs or symptoms referable to cerebral venous thrombosis were examined by both conventional MRI, TOF MRV and CE-MRV. Furthermore, ten subjects with cerebral venous thrombosis underwent the same MRI examination. These patients had been admitted to our institution over a period of 3 years (six female, four male; ages: 8 to 63 years). All were referred because of signs and symptoms highly suggestive of cerebral venous thrombosis. They were at first seen on admission by a physician of the stroke unit who was trained in the acute examination of patients with stroke. The final diagnosis was made on the basis of imaging and clinical findings. The final diagnosis as reported in the discharge report was used. All patients underwent both TOF and CE-MRV of the brain. In addition to clinical examination, all patients underwent correlative imaging: nine were given CT scans of the brain (within 1 to 7 h of having MRI), five underwent cerebral catheter angiography (within 1.5 to 18 h of MRI) with late venous images and four of the total had both CT and angiography.

MRI was performed by a 1.5-T echo-planar-capable commercial clinical scanner (Magnetom Vision, Siemens Medical Systems, Erlangen, Germany) equipped with a gradient overdrive with a non-resonant 180-mT/m/ms slew rate and a 25-mT/m peak-amplitude whole-body gradient; the imaging was done with a circularly polarized head coil. Conventional imaging consisting of axial T1-, T2- and proton-density (PD)-weighted imaging [spin-echo T1-weighting (TE = 12 ms, TR = 528 ms, matrix 96×200, NEX = 2) and turbo-spin-echo T2-/PD-weighting (TE = 98/16 ms, TR = 3,176, matrix 180×256, 5-mm-thick slices, NEX = 2)] followed by coronal T2-weighted imaging (TR = 3,640 ms, TE = 96 ms, 4.0-mm-thick slice, FoV = 160×160, matrix = 280×512, 2 NE) were carried out; finally MRV of the brain was performed. At first an unenhanced TOF MRV sequence was used: TR = 30 ms, TE = 9.0 ms, TA = 8 min, field of view = 175×200 mm, matrix = 225×256 pixels; image were acquired in the coronal plane and the saturation slab was placed below the images in the region of the neck to obtain venous images. Subsequently, CE-MRV was performed using a modified 3D first-pass MRA sequence with the following parameters: TR = 7.8 ms, TE = 3.5 ms, 10 to 15 s per volume with the acquisition being repeated four times; imaging was performed in the coronal plane. Contrast material (Magnevist, Schering, Berlin, Germany) was administered over a cubital vein, and was injected with a power injector (Medrad Spectris), with a total of 20 ml being administered over 4 s. For the CE-MRV images, in order to obtain the best venous contrast filling, after having manually inspected the MR source images to establish where venous contrast was the highest, we usually subtracted the fourth sequence from the first, and the subtraction image was then used. Both MRV sequences were then post-processed by using the maximum projection algorithm and were subsequently filmed in rotating projections around the vertical plane, with a total of 12 images over 180°.

The images were then viewed by two independent radiologists who scored them according to a slightly modified system of Loubeyre et al. [22]: the scale is graded from 0 to 4 (0 = vessel not identified; 1 = vessel identified but not clearly defined along its entire length; 2 = vessel clearly identified but with a focal filling defect; 3 = vessel clearly identified but with a narrowing; 4 = vessel clearly identified and defined along its entire length). The veins studied were the superior group (comprising the superior sagittal sinus, the inferior sagittal sinus, the confluens, the transverse sinuses and the sigmoid sinuses), the inferior group (comprising the cavernous sinuses, the superior and inferior petrosal sinuses and the sphenoparietal sinuses), the deep venous system (comprising the internal cerebral veins, the basal veins of Rosenthal, the vein of Galen, the confluence of the vein of Galen) and the cortical venous system (comprising the veins of Trolard and Labbé), with scores being allocated according to visualization of the vessel. Concerning the scoring, at first the CE-MRV and the TOF images were assessed separately by each observer and the interobserver variability was calculated, which was below 3% for all veins. Then the MRV readings of both observers were pooled according to sequence (CE-MRV or TOF) and the two different methods were evaluated by the Mann-Whitney U-test.

Results

Volunteer studies

Imaging time was drastically reduced when CE-MRV (4×15 s per acquisition for a total of 60 s for each patient) was compared with the TOF technique (8 min).

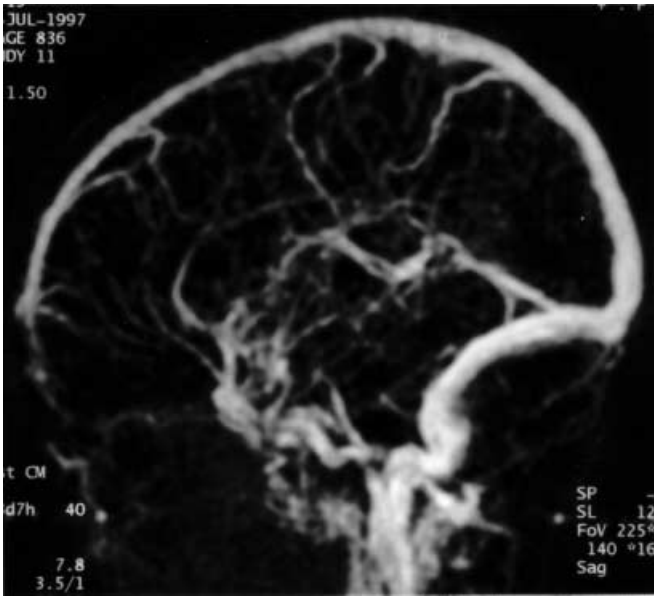


Fig. 1. Lateral projection of a CE-MRV in a control subject, which provides a complete demonstration of the cerebral veins, ranging frontally from the anterior portions of the superior sagittal sinus, to caudally in the region of the neck veins. The sinus rectus and the deep cerebral veins are also well visualized, and the cortical veins are well displayed. Additionally, there is filling of numerous cortical veins and of the cavernous sinus

CE-MRV allowed extensive coverage of the brain vasculature: there was coverage frontally of the superior sagittal sinus and caudally into the veins of the neck (Fig. 1).

CE-MRV and TOF MRV demonstrated equally well in all cases the superior sagittal sinus, the inferior sagittal sinus, the straight sinus and the transverse and sigmoid sinuses. We found that while TOF MRV was able to demonstrate reliably the greater venous system of the brain, CE-MRV was able to demonstrate better detail of the cortical veins (Fig. 2).

Also, we found that in a number of cases, there was a better filling of the veins with CE-MRV, especially in regions where turbulent flow might be encountered, such as close to the confluens sinuum, where at times diminished signal could be observed by TOF techniques (Fig. 2).

Concerning the scoring, at first the CE-MRV and the TOF images were evaluated separately by each observer, and the interobserver variability was calculated, which was below 3% for all veins. Then the MRV readings of both observers were pooled according to sequence (CE-MRV or TOF) and the two different methods were evaluated by the Mann-Whitney U-test. There was an overall higher score for the CE-MRV for all groups (Fig. 3): for the superior group $P < 0.000000$, for the inferior group $P = 0.000065$, for the deep venous system $P = 0.000000$ and for the cortical venous group, $P < 0.00000$.

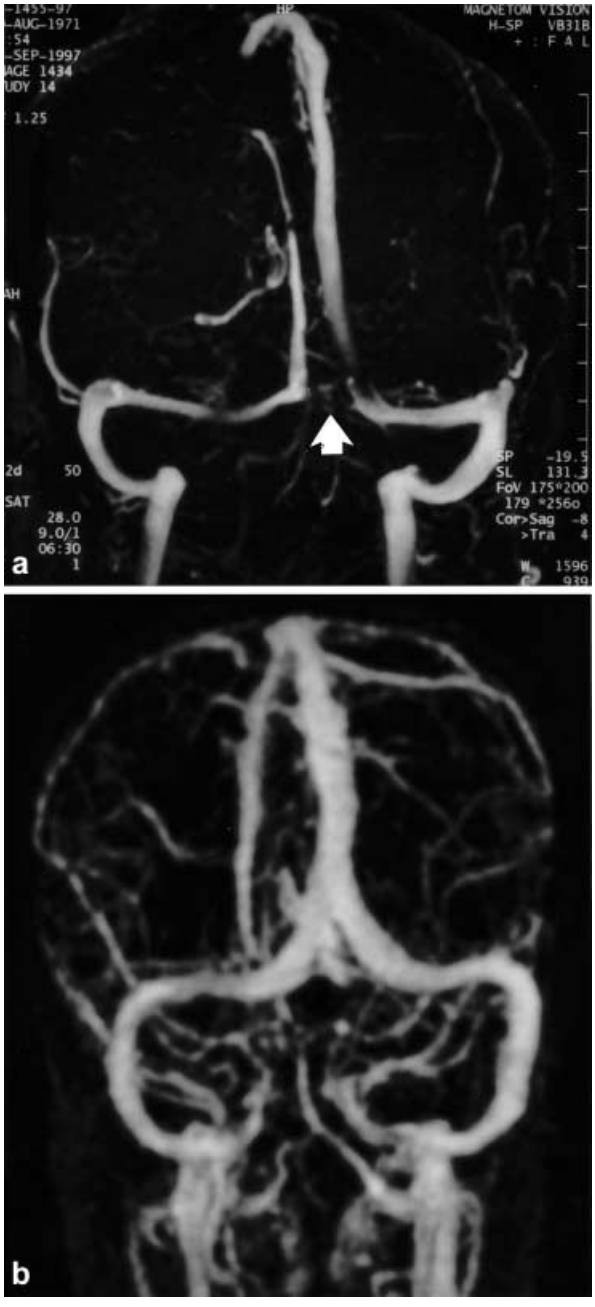


Fig. 2a, b. Control subject. **a** On the TOF MRV there is slight less filling of the superior sagittal sinus at the level of the confluens (*white arrow*), which is filled with contrast on **b** CE-MRV images, therefore not corresponding to a thrombosis

Venous thrombosis patients

In the patients with venous thrombosis, both methods were found to allow positive visualization of the thromboses in all ten cases (100%). The thromboses were localized as follows: in five cases the thrombi were localized in the superior sagittal sinus, in three cases, in the transverse sinus, in one case it was in the sinus

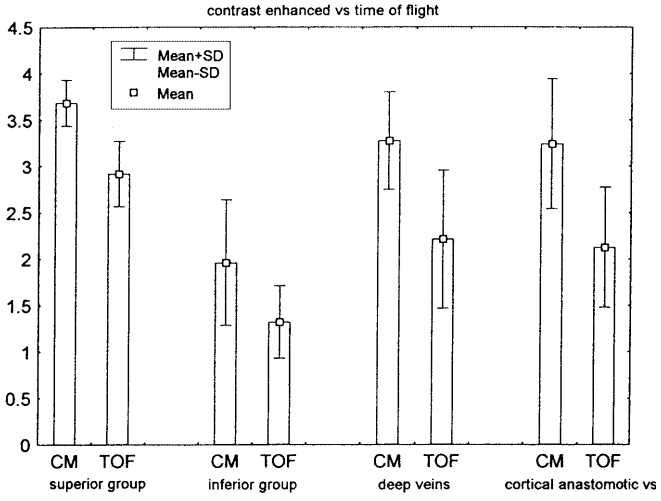


Fig. 3. Graph demonstrating score differences for CE-MRV (*left rows*) versus TOF venography (*right rows*) for the four different venous groups (*left to right*: superior group, inferior group, deep veins and cortical veins) in the volunteers. In all groups the scores obtained by CE-MRV are significantly higher

rectus, and in one other case it was a bridging vein which was thrombosed. In the cases of thromboses of the superior sagittal sinus, CE-MRV could show that in 4/5 cases there was partial occlusion of the affected superior sagittal sinus (Figs. 4 and 5), whereas the TOF techniques had revealed no flow signal at all; also CE-MRV could clearly demonstrate the presence of increased cortical collateral drainage in these cases, while it could not be seen so well with the TOF technique.

CE-MRV could also demonstrate better the presence of supplementary cortical venous drainage seen in some cases (Figs. 6 and 7), as well as demonstrate venous congestion in one case of cortical venous occlusion (Fig. 8).

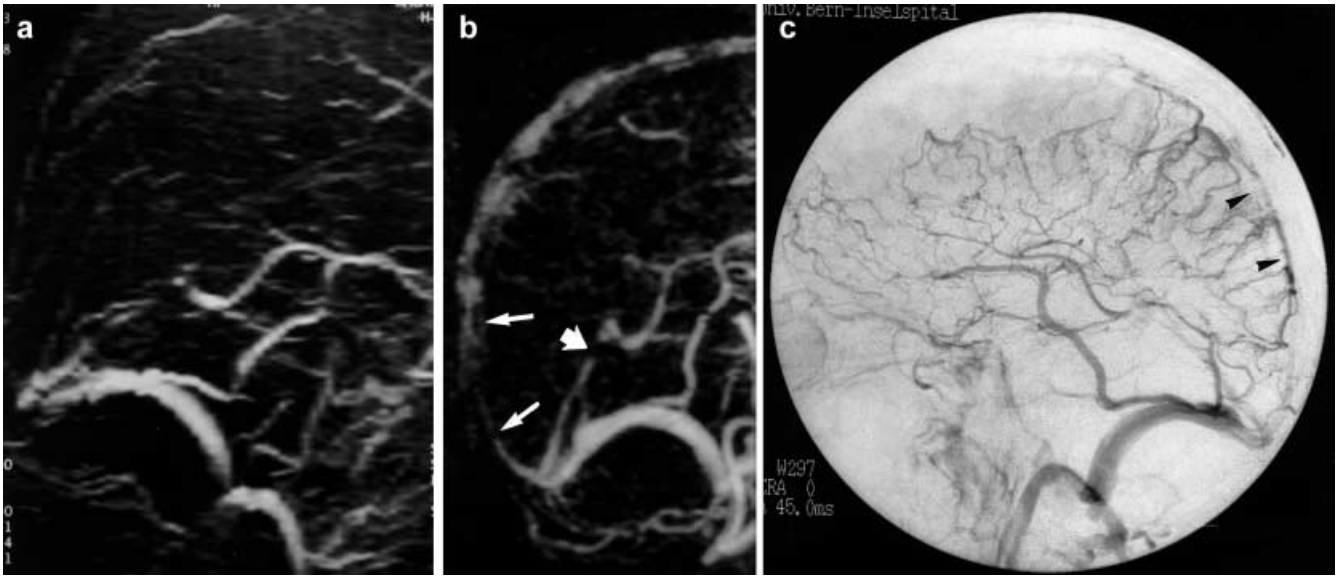
Computed tomography

CT was available in nine cases and was positive in all patients. In the seven cases of superior sagittal and transverse sinus thrombosis we could observe a typical slight hyperdensity on unenhanced images with a central area of lesser enhancement after intravenous contrast application (delta sign). In the case with a thrombosis of the straight sinus alone there was marked hyperdensity of the sinus on unenhanced images and diminished enhancement; in the case of bridging vein thrombosis there was a hyperdense cortical vein to be seen on unenhanced images.

Magnetic resonance imaging

In the seven cases of thrombosis of the superior sagittal sinus or transverse sinus, changes in signal attributable to thrombosis could be seen as either an increase in T1-weighted signal in the affected sinus (two cases) or as a mixture of T1-hyperintensity and T2-weighted hyperintensity (five cases); in the cases of straight sinus and

Fig. 4a–c. A 55-year-old male patient with thrombosis of the superior sagittal sinus. **a** Lateral projection TOF MRV demonstrates absence of signal in the affected vein, while **b** CE-MRV demonstrates that while the vessel is occluded, it is only partially so: there are multiple filling defects along the length of the superior sagittal sinus, along with remaining flow (*thin white arrows*). In both sequences there is also partial obliteration of the straight sinus (*thick white arrow*). **c** The findings of the CE-MRV were confirmed by cerebral angiography where we can see that the superior sagittal sinus is not completely occluded but only partially so, with flow being present in the sinus (*small black arrowheads*)



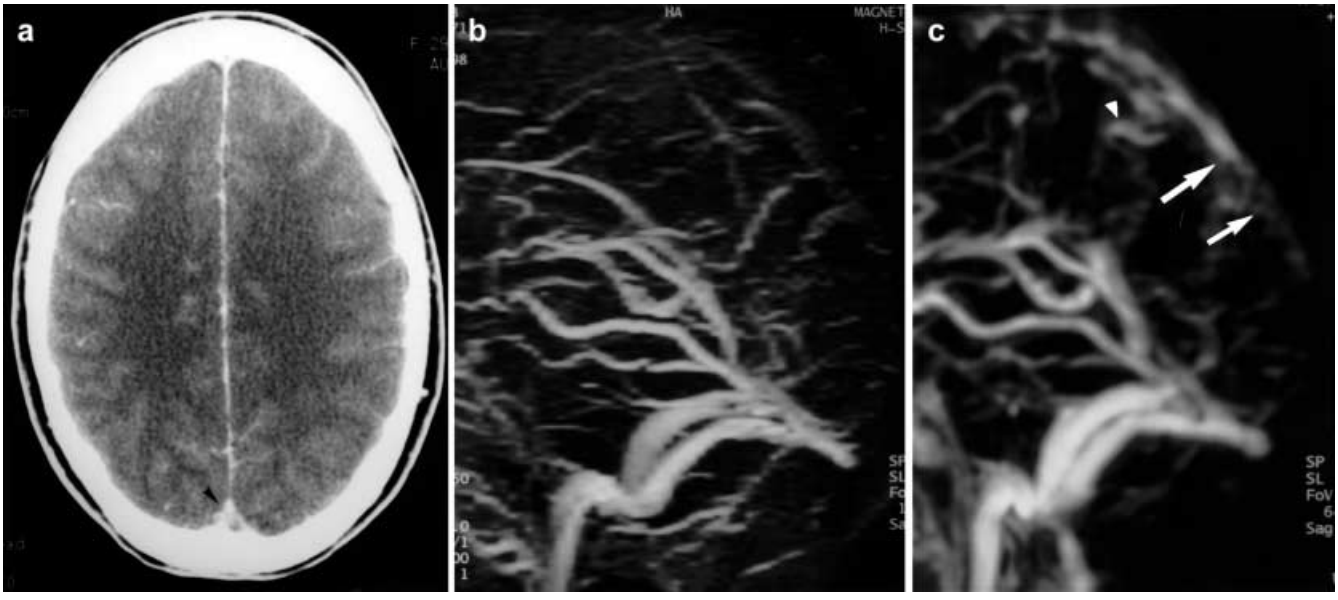


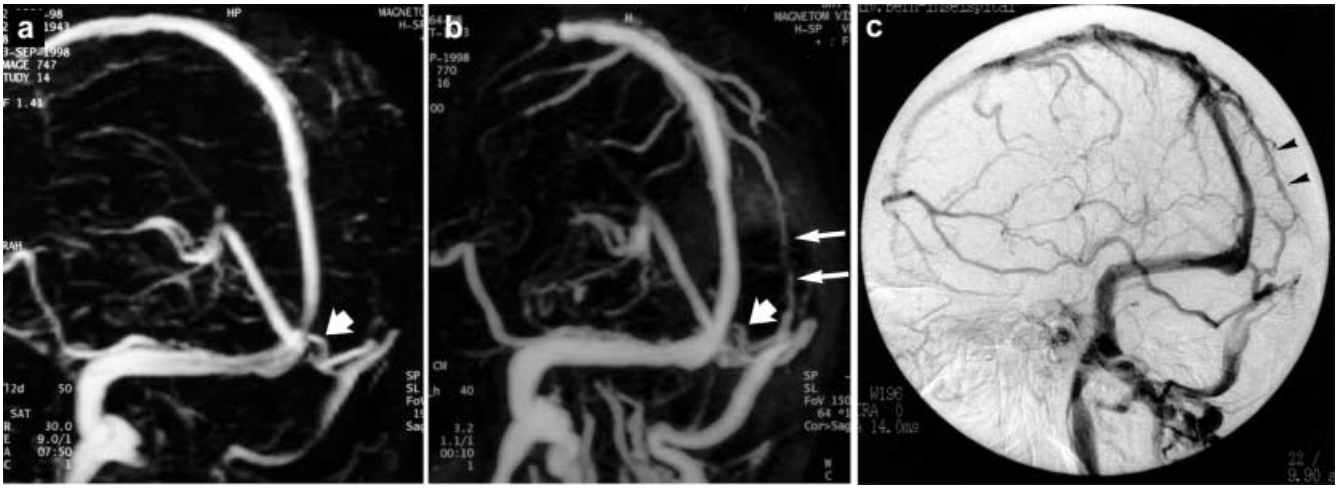
Fig. 5a–c. A 28-year-old female patient with thrombosis of the superior sagittal sinus. **a** CT shows a partial delta sign in the posterior part of the superior sagittal sinus (*small black arrowhead*); **b** TOF MRV does not show any flow in the superior sagittal sinus whereas **c** the CE-MRV demonstrates partial flow in a part of the superior sagittal sinus (*white arrows*) along with the presence of dilated venous superficial collaterals (*white arrowhead*)

bridging vein sinus, there was only T2-weighted hyperintensity as a sign of diminished flow void to be clearly seen.

Fig. 6a–c. A 54-year-old female patient with partial occlusion of the transverse and sigmoid sinuses on the left side. **a** The TOF MRV demonstrates thinning of the left transverse and sigmoid sinuses (*thick white arrow*), which is also shown on CE-MRV. **b** CE-MRV also demonstrates the presence of collateral venous (*thin white arrows*) channels between the superior sagittal sinus and the left transverse sinus which could not be seen on the TOF MRV, but which are confirmed by **c** cerebral angiography (*black arrowheads*)

Discussion

We have demonstrated that CE-MRV can reliably show the complete intracranial venous vasculature in a short time, and that it compares favourably with conventional TOF methods. Comparing it with TOF methods, we can see partially obstructed sinuses better, whereas TOF shows complete obstruction, and CE-MRA can also reliably demonstrate increased collateralization. Methods such as the late images of digital subtraction roentgen angiography, CT where an empty delta sign can be visualized, can be helpful but require contrast or are invasive. While digital subtraction angiography (DSA) is the gold standard method it is time consuming and invasive; CT is very often very quickly available in the emergency setting in most hospitals and is easily interpretable but requires iodine contrast administration. MR studies have been able to demonstrate secondary parenchymal changes due



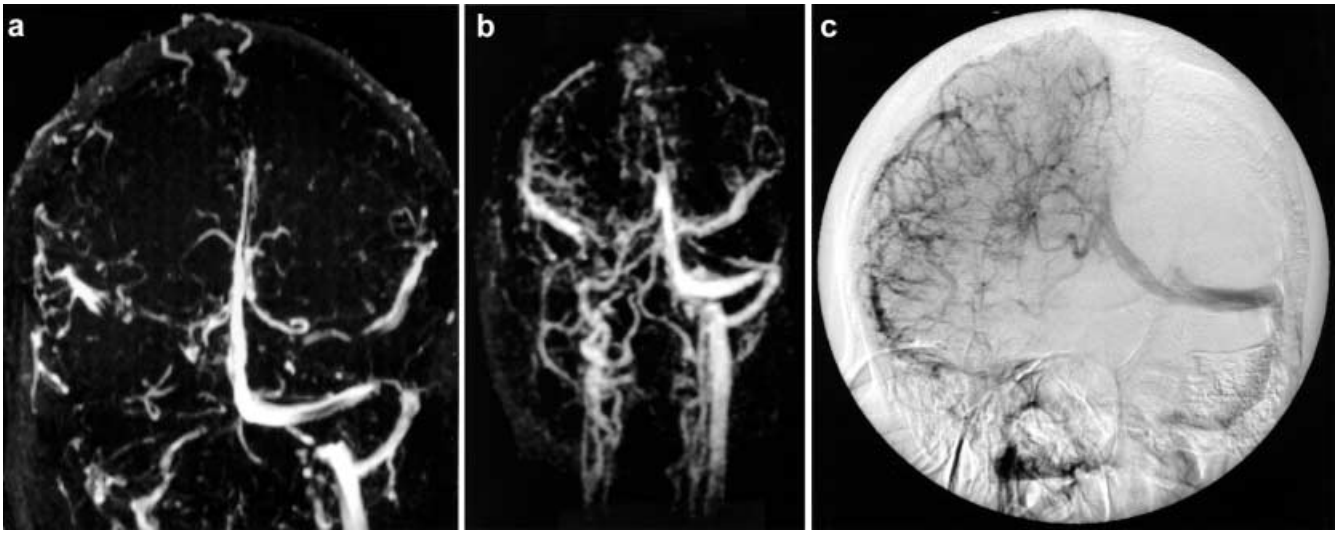


Fig. 7a–c. Thrombosis of the superior sagittal and right transverse sinuses in a 20-year-old female patient. **a** TOF MRV shows absence of parts of the superior sagittal sinus and right transverse sinus; **b** CE-MRV does demonstrate the same findings with additional cortical venous collaterals, more prominent on the affected right side. **c** Cerebral angiography demonstrates the occlusion as well as the extensive collateralization

to the presence of venous congestion, ranging from swelling with or without T2-weighted changes to haemorrhage. With MRI it is also possible to utilize the flow-sensitive aspects of spin-echo sequences in order to suggest the diagnosis: in the presence of sinus thrombosis, on conventional planar MR imaging, at first, slight hyperintensity on T1-weighted images is noted followed by both hyperintensity on T1- and T2-weighted images in a later stage; recanalization at a later stage is followed by reappearance of the flow void [23]. It is possible to demonstrate the clot by obtaining additional post-contrast T1-weighted images. There is, however, one serious pitfall with this technique: Dormont et al. found that the thrombus in patients with chronic occlusion might enhance, leading eventually to false-negative results due to the filling of a recanalization network [24].

MRV now allows the non-invasive demonstration of the veins of the brain. However, these sequences are time consuming, with total imaging taking up to 9 min. Mainly two approaches are used: those based on TOF techniques and those which use phase-sensitive sequences; while phase-sensitive sequences have the distinct advantage of being able to demonstrate slow flow, TOF techniques have become more established, since they are usually less time consuming. When studying anatomy, Loubeyre et al. found that phase-contrast MR techniques could demonstrate the venous vessels well [22].

A recent study showed that it was better to perform studies with 3D phase-contrast and coronal 2D TOF MRA than with transverse or sagittal 2D TOF MRA; since our imaging is also performed in the coronal plane, this probably also reflects our good results [25].

Chakeres et al. studied CE-MRV with acquisition times of 3.5 min and found that they were able to improve imaging of the venous system and reduce acquisition times in a significant way, with better anatomy of small cortical veins [26]. We confirm that CE-MRV provides an improved display of cortical veins, especially in cases of venous obstruction, when there is cortical collateral venous drainage.

The deep veins as well as the cortical veins could be as well demonstrated by both methods, with a slight superiority for the CE-MRV technique, even if the deep venous system has fewer collateral possibilities for drainage [27].

CE-MRV is significantly faster than TOF MRV, demonstrates small venous anatomy better despite the lower spatial resolution, covers a larger area, along with the draining neck veins and the anterior portion of the superior sagittal sinus, and demonstrates thrombosis as well as TOF methods do. The luminographic effect obtained by CE-MRV is also much better. This new method might allow a faster and more accurate workup towards efficient therapy [14]. MRI also has the distinct advantage of being able to provide further anatomical and physiological information: in addition to the tissular changes found in cerebral venous thrombosis, usually due to stasis and oedema, newer techniques such as diffusion and perfusion-weighted imaging might provide information about tissue viability.

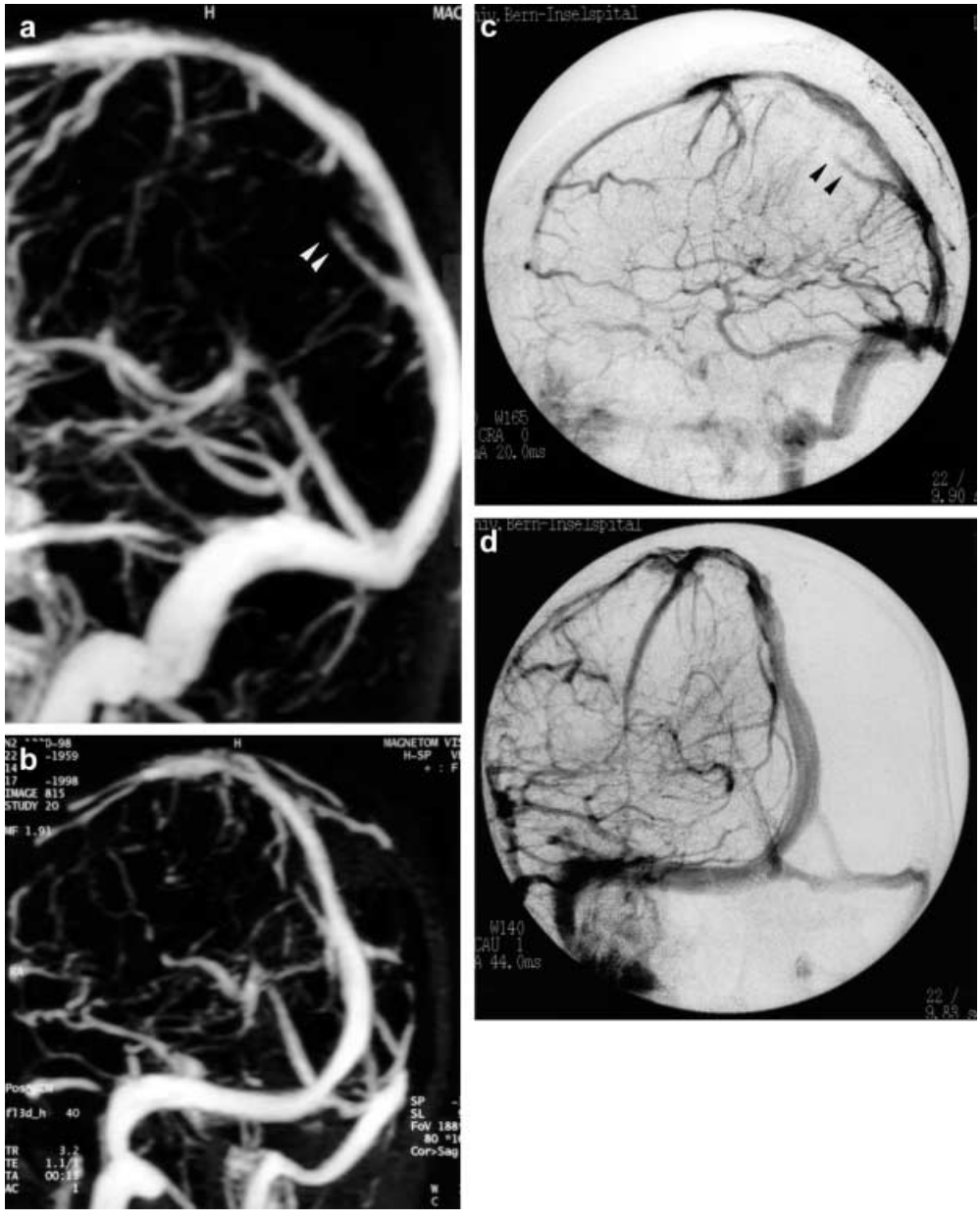


Fig. 8a–d. A 39-year-old male patient with a cortical venous thrombosis. The CE-MRV demonstrates an occluded, or irregular, cortical vein with less contrast filling in **a** the lateral (*white arrowheads*) and **b** oblique projections, which is confirmed by **c**, **d** cerebral pan-angiography where this slightly tortuous and dilated vein is demonstrated. There is also less parenchymal filling distal to the vein (*black arrowheads*)

References

1. Bousser MG, Russell RR (eds) (1997) Cerebral venous thrombosis. Saunders, London
2. Bousser MG, Chiras J, Bories J, Castaigne P (1985) Cerebral venous thrombosis – a review of 38 cases. Stroke 16:199–213
3. Crawford SC, Digre KB, Palmer CA, Bell DA, Osborn AG (1995) Thrombosis of the deep venous drainage of the brain in adults. Analysis of seven cases with review of the literature. Arch Neurol 52:1101–1108
4. De Bruijn SFTM, Stam J, Kappelle LJ (1996) Thunderclap headache as first symptom of cerebral venous thrombosis. J Neuroradiol 21:72–80

5. Villringer A, Mehraein S, Einhäupl KM (1994) Pathophysiological aspects of cerebral sinus venous thrombosis. J Neuroradiol 21:72–80
6. De Bruijn SFTM, Stam J, for the cerebral venous sinus thrombosis study group (1999) Randomized, placebo-controlled trial of anticoagulant treatment with low-molecular-weight heparin for cerebral sinus thrombosis. Stroke 30:484–488
7. Horowitz M, Purdy P, Unwin H, Carstens G, Greenlee R, Hise J, Kopitnik T, Batjer H, Rollins N, Samson D (1995) Treatment of dural sinus thrombosis using selective catheterization and urokinase. Ann Neurol 38:58–67
8. Tsai FY, Higashida RT, Matovich V, Alfieri (1992) Acute thrombosis of the intracranial dural sinus: direct thrombolytic treatment. Am J Neuroradiol 13:1304–1317
9. Buonanno FS, Moody DM, Ball MR, Laster DW (1978) Computed cranial tomographic findings in cerebral sinovenous occlusion. J Comput Assist Tomogr 2:281–290
10. Chiras J, Bousser MG, Meder JF, Koussa A, Bories J (1989) CT in cerebral thrombophlebitis. Neuroradiology 27:145–154
11. Sze G, Simmons B, Krol G, Walker R, Zimmerman RD, Deck MDF (1988) Dural sinus thrombosis: verification with spin-echo techniques. Am J Neuroradiol 9:679–686
12. Yuh WT, Simonson TM, Wang AM, Koci TM, Tali ET, Fisher DJ, Simon JH, Jinkins JR, Tsai F (1994) Venous sinus occlusive disease: MR findings. Am J Neuroradiol 15:309–316
13. Daniels DL, Czervionke LF, Hendrix LE, Mark LP, Smith DF, Meyer GA, Maiman DJ, Haughton VM, Williams AL (1989) Gradient recalled echo MR imaging of superior sagittal sinus occlusion. Neuroradiology 31:134–136
14. Mattle HP, Wentz KU, Edelman RR, Wallner B, Finn JP, Barnes P, Atkinson DJ, Kleefield J, Hoogewoud HM (1991) Cerebral venography with MR. Radiology 178:453–458
15. Vogl TJ, Bergman C, Villringer A, Einhäupl K, Lissner J, Felix R (1994) Dural sinus thrombosis: value of venous MR angiography for diagnosis and follow-up. Am J Roentgenol 162:1191–1198
16. Ozsvath RR, Casey SO, Lustrin ES, Alberico RA, Hassankhani A, Patel M (1997) Cerebral venography: comparison of CT and MR projection venography. Am J Roentgenol 169:1699–1707
17. Yousem DM, Balakrishnan J, Debrun GM, Bryan RN (1990) Hyperintense thrombus on GRASS MR images: potential pitfall in flow evaluation. Am J Neuroradiol 11:51–58
18. Tsuruda J, Saloner D, Norman D (1992) Artifacts associated with MR neuroangiography. Am J Neuroradiol 13:1411–1422
19. Nadel L, Braun IF, Kraft KA, Jensen ME, Laine FJ (1990) MRI of intracranial sinovenous thrombosis: the role of phase imaging. Magn Reson Imaging 8:315–320
20. Casey SO, Alberico RA, Patel M, Jimenez JM, Ozsvath RR, Maguire WM, Taylor ML (1996) Cerebral CT venography. Radiology 198:163–170
21. Remonda L, Heid O, Schroth G (1998) Carotid artery stenosis, occlusion and pseudo-occlusion: first-pass, gadolinium-enhanced, three-dimensional MR angiography – preliminary results. Radiology 209:95–102
22. Loubeyre P, De Jaegere T, Tran-Minh VA (1999) Three-dimensional phase contrast MR cerebral venography with zero filling interpolation in the slice encoding direction. Magn Reson Imaging 17:1227–1233
23. Macchi PJ, Grossman RI, Gomori JM, Goldberg HI, Zimmerman RA, Bilaniuk LT (1986) High field MR imaging of cerebral venous thrombosis. J Comput Assist Tomogr 10:10–15
24. Dormont D, Sag K, Biondi A, Wechsler B, Marsault C (1995) Gadolinium-enhanced MR of chronic dural sinus thrombosis. Am J Neuroradiol 16:1347–1352
25. Liauw L, van Buchem MA, Spilt A, de Bruïne FT, van den Berg R, Hermans J, Wasser MNJM (2000) MR angiography of the intracranial venous system. Radiology 214:678–682
26. Chakeres DW, Schmalbrock P, Brogan M, Yuan C, Cohen L (1990) Normal venous anatomy of the brain: demonstration with gadopentetate dimeglumine in enhanced 3-D MR angiography. Am J Neuroradiol 11:1107–1118
27. Lafitte F, Boukobza M, Guichard JP, Reizine D, Woimant F, Merland JJ (1999) Deep cerebral venous thrombosis: imaging in eight cases. Neuroradiology 41:410–418