

Visualization of the normal cerebral venous system using a contrast-enhanced three-dimensional magnetic resonance angiography technique

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SUMMARY

Ultrafast contrast-enhanced (CE) 3D Magnetic resonance angiography has been used recently to image the cerebral venous system. It was necessary to assess its reliability in imaging the normal cerebral venous structures in order to determine its usefulness for evaluating pathological conditions. The objectives of this study were to determine the frequency of visualization of dural sinuses and intracranial veins and the distribution of transverse sinus dominance, and to correlate these with reported values. Our study comprised 98 patients who had both normal brain MRI and MR venography. T1- and T2-weighted spin-echo images, fluid attenuation inversion recovery (FLAIR) sequences, and CE 3D Turbo-flash MRA images were acquired. According to the quality of visualization, the dural sinuses and cerebral veins were classified into four grades and the distribution of transverse sinus dominance was determined. Complete coverage of the cerebral venous system was obtained in 60s. The large dural sinuses, the vein of Galen, and the internal cerebral veins were completely visualized in all cases. The inferior sagittal sinus, the thalamostriate veins, the basal veins of Rosenthal, and the veins of Trolard and Labbé were seen either completely or partially in 61%, 86%, 90%,

98%, and 85% of cases, respectively. The transverse sinus was right, left, and codominant in 58%, 19%, and 23% of cases, respectively. We found that our results were in excellent agreement with the reported values. CE 3D turbo-flash MRA, however, offers the advantage of a shorter examination time.

Key words: Cerebral venography – Cerebral veins – Cerebral blood vessels – MRA – MRV

INTRODUCTION

For many years, digital subtraction angiography (DSA) has been the standard imaging modality of the cerebral venous system, even after the introduction of computed tomography. The long examination time and the invasive nature of the procedure, however, make it undesirable for screening purposes. Several studies have demonstrated that there is a good correlation between DSA and MR venography (Mattle et al., 1991; Casey et al., 1996; Liang et al., 2001). Currently, magnetic resonance angiography (MRA) has become a widely used technique and is considered the modality of choice for imaging the cerebral venous system, since it is both noninvasive and less time-consuming (Liau et al., 2000; Özsarlak et al., 2004).

Several MRA techniques, such as time-of-flight (TOF), phase-contrast (PC) angiography, and recently, contrast-enhanced (CE) 3D gradient-echo sequences, have been used to image the cerebral venous system. However, the MRA techniques are not without limitations, which vary according to the technique (Casy et al., 1996; Reichenbach et al., 1997; Wetzell et al., 1999; Liang et al., 2001). TOF and PC techniques require long examination times, and this represents an important limitation to these techniques. It is mandatory to involve an MRA technique that requires a very short acquisition time particularly in ill and uncooperative patients. The objectives of this study were to determine the frequency of visualization of normal cerebral dural sinuses and veins, to identify the distribution of dominance of transverse sinuses using CE 3D Turbo-flash MRA, and to correlate our findings with those reported in the literature.

MATERIALS AND METHODS

Our study was performed on 98 patients (45 male, 53 female; age range: 2 months to 76 years; mean age: 27 years). The study group was restricted to patients who had no abnormal brain MRI findings and normal CE MR venography. Patients with findings consistent with dural sinus thrombosis, brain tumor, or arterio-venous malformation were excluded from this study.

The study was performed on a clinical 1.5 Tesla system (Superconducting Magnetom Vision Plus, Siemens, Germany) using the standard circular polarized head coil.

The imaging protocol included T1- and T2-weighted axial spin-echo (SE) imaging and fluid attenuation inversion recovery (FLAIR) sequences acquired in the coronal plane, and CE 3D Turbo-flash MRA images acquired in the sagittal plane. The imaging parameters for CE 3D Turbo-flash MRA were: TR/TE of 4.6/1.8 ms, 25° flip angle, slab thickness of 130 mm, 1 excitation, 125 x 256 matrix, 26 cm field of view. Since we did not have a care-bolus sequence, a delay time of 20 s between bolus injection of gadopentate dimeglumine (GD) and data acquisition was used. Two acquisitions of 20 s each were obtained, such that the total examination time was 60 s. A dose of 0.1 mmol GD (Magnevist, Shering AG, Germany) was automatically injected at a rate of 2 ml/s.

All the MR angiograms were displayed using the maximum intensity projection (MIP) algorithm. Multiplanar reconstructed images were obtained in the transverse and sagittal planes. Two experienced radiologists working in consensus reviewed the MIP images on hard copy films. The MIP images of the dural sinuses and veins were viewed for quality of visualization. The dural sinuses and veins were graded as follows: Grade A: when the sinus or vein was completely visualized and intense; Grade B: when the sinus or vein was completely visualized but faint; Grade C: if the sinus or vein was incompletely visualized, and Grade D: when the sinus or vein was not visualized along its entire course.

In paired dural sinuses, the sinus was considered non-dominant if its diameter was reduced by more than 25% compared with the contralateral side (some patients with grades A, B, and all patients with grade C); hypoplastic if reduced by more than 75% (some patients with grades A, B, and all patients with grade C), and aplastic if the sinus was not completely visualized (patients with grade D) and in absence of venous collateral circulation. The unpaired sinuses were considered hypoplastic and aplastic if they were graded C and D, respectively. The visualization percentage of the different dural sinuses and veins and the dominance of lateral sinuses were determined.

RESULTS

CE 3D Turbo-flash MRA allowed complete coverage of the cerebral venous system; the superior sagittal sinus was covered anteriorly and the proximal portion of the jugular veins was covered posteriorly (Fig. 1).

The quality of visualization of intracranial dural sinuses is shown in Table 1 and that of deep and cortical cerebral veins in Table 2.

Complete intense visualization (grade A) of the dural sinuses and of the deep and cortical cerebral veins was achieved in 80%, 65%, and 42% of cases, respectively.

Complete visualization of the dural sinuses, either intense or faint (grades A and B), was obtained in 82% of cases. The superior sagittal, straight, transverse, and sigmoid sinuses were completely visualized in all cases except one, which had partial agenesis of the anterior portion of the superior sagittal sinus (Fig. 2). The inferior sagittal and occipital sinuses were

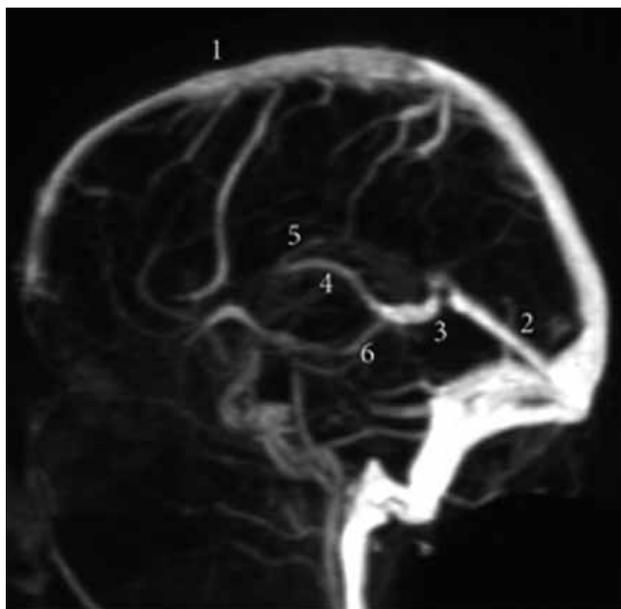


Fig. 1a

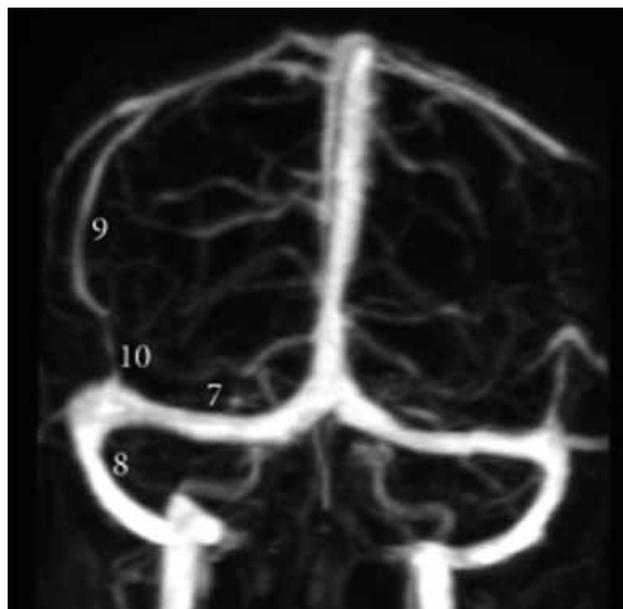


Fig. 1b

Fig. 1. Complete visualization of the cerebral venous system as shown on sagittal (a) and coronal (b) MIP images obtained with the CE 3D turbo-flash MRA sequence. 1: superior sagittal sinus. 2: straight sinus. 3: vein of Galen. 4: internal cerebral veins. 5: thalamostriate veins. 6: basal veins of Rosenthal. 7: transverse sinus. 8: sigmoid sinus. 9: vein of Trolard. 10: vein of Labbé. Note aplasia of inferior sagittal sinus.

completely visualized in 33% and 21% of cases; they were hypoplastic in 28% and 13% of cases, and aplastic in 39% and 66% of cases, respectively.

Table 1. Visualization quality of dural sinuses in 98 patients.

Sinus	Grade			
	A	B	C	D
Superior sagittal sinus	98 (100%)	-	-	-
Straight sinus	85 (87%)	13 (13%)	-	-
Right transverse sinus	89 (91%)	9 (9%)	-	-
Left transverse sinus	86 (88%)	12 (12%)	-	-
Right sigmoid sinus	90 (92%)	8 (8%)	-	-
Left sigmoid sinus	92 (94%)	6 (6%)	-	-
Inferior sagittal sinus	7 (7%)	25 (25%)	28 (29%)	38 (39%)
Occipital sinus	4 (4%)	16 (17%)	13 (13%)	65 (66%)

Table 2. Visualization quality of deep and cortical cerebral veins in 98 patients.

Vein	Grade			
	A	B	C	D
Vein of Galen	96 (98%)	2 (2%)	-	-
Internal cerebral veins	86 (88%)	10 (10%)	2 (2%)	-
Thalamostriate veins	34 (35%)	16 (16%)	33 (34%)	15 (15%)
Veins of Rosenthal	39 (40%)	40 (41%)	8 (8%)	11 (11%)
Vein of Labbé	35 (36%)	20 (20%)	28 (29%)	15 (15%)
Vein of Trolard	46 (47%)	14 (14%)	35 (36%)	3 (3%)

The transverse sinus was found to be right, left, and codominant in 58%, 19%, and 23% of cases, respectively. The right and left transverse sinuses were hypoplastic in 5% and 6% of cases, respectively (Fig. 3). No aplastic lateral sinus was detected.

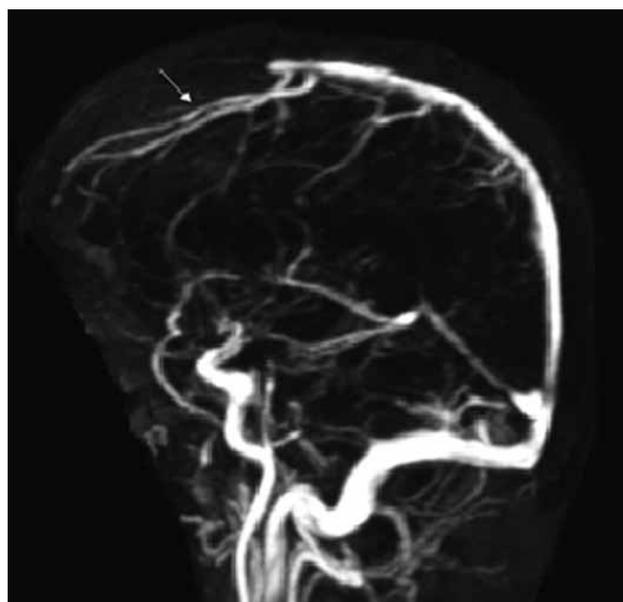


Fig. 2

Fig. 2. Sagittal MIP image acquired in the sagittal plane shows agenesis of the anterior portion of the superior sagittal sinus in an adult patient. Note the dilated anterior draining cortical veins joining the superior sagittal sinus caudally (arrow).

The quality of visualization of the deep cerebral veins was complete (grades A and B) in 82% of cases. The vein of Galen and paired internal cerebral veins were completely visualized in all cases. The paired thalamostriate veins and the basal veins of Rosenthal were completely visualized in 51% and 81% of



Fig. 3a



Fig. 3b

Fig. 3. Coronal MIP images acquired in the sagittal plane show non-dominant left lateral sinuses. a: reduction in diameter greater than 25% and in b: greater than 75% (hypoplastic) compared with the contralateral side.

cases; they were hypoplastic in 34% and 8% of cases, and aplastic in 15% and 11% of cases, respectively.

Complete visualization of paired cortical cerebral veins (grades A and B) was obtained in 59% of cases. The veins of Trolard and Labbé were completely visualized in 62% and 56% of cases, they were hypoplastic in 36% and 29% of cases, and aplastic in 2% and 15% of cases, respectively.

DISCUSSION

MRV allows non-invasive visualization of the intracranial venous system. For this purpose, TOF and PC MRV have been the standard sequences practiced during the past decade. The artifacts related to these techniques are now well known and have been documented in several studies. TOF is sensitive to spin saturation related to the imaging plane and cannot discriminate between hypoplastic and thrombosed sinuses; PC is sensitive to turbulence of flow, which results in marked intravascular signal loss due to intra-voxel dephasing (Petersen and Klose, 1997; Ayanzen et al., 2000; Liang et al., 2001; Lövblad et al., 2002; Kirchof et al., 2002; Farb et al., 2003).

In the last few years, a change in the strategy of MR imaging of the cerebral venous system has occurred with a shift from TOF and PC MRV towards CE techniques. These techniques have been shown to provide better imaging of the cerebral venous system as compared with TOF and PC techniques (Liang et al., 2001; Lövblad et al., 2002; Kirchof et al., 2002; Özsarlak et al., 2004; Rollins et al., 2005). Magnetic resonance contrast agents enable both higher-resolution 3D imaging and a shortening of T1 of the blood, such that the steady-state signal intensity of the blood becomes much higher than the signal intensity of the stationary tissues (Yusel et al., 1999; Yang et al., 2002) and consequently appears greatly enhanced irrespective of the flow pattern or velocity. Therefore, the technical artifacts related to the TOF and PC sequences are not encountered (Bosmans and Marchal, 1996; Duran et al., 2002).

Ideally, MR imaging of the cerebral venous system should fulfill two essential conditions: an absence of technical artifacts, to allow proper image interpretation, and a short examination time, which permits increased patient comfort and reduces motion artifacts. These criteria are important for patients who are imaged for possible venous thrombosis, as they are often ill and not fully cooperative.

CE 3D Turbo-flash MRV is a fast low-angle shot sequence that uses asymmetrical echo encoding in the readout direction, such that the number of phase-encoding steps can be reduced by means of asymmetrical sampling. This technique permits a short imaging time, and therefore results in a reduction of motion artifacts (Mitsuzaki et al., 2000). Our study demonstrated that CE 3D Turbo-flash MRV allows imaging of the cerebral venous system within 60 s and that it compares favorably with other CE techniques, such as magnetization prepared-rapid acquisition gradient-echo sequence (MP-RAGE), which requires more than seven min (Liang et al., 2001; Liang et al., 2002), and the recently described auto-triggered elliptic centric-ordered sequence (ATECO) (Farb et al., 2003), which requires more than four min. In addition, CE 3D Turbo-flash MRV provides a thick slab of 13 cm that covers the entire brain. Kirchhof et al. (2002) argue that the use of a thick slab has an unfavorable effect on the spatial resolution, such that minimal irregularities or partial filling defects could be missed. Despite the low spatial resolution, we believe that the use of a thick slab is an advantage rather than a disadvantage since it is better to visualize a sinus completely than partially; it also compares favorably with the higher-spatial resolution TOF technique, where the anterior or posterior portions of the superior sagittal sinus may not be well visualized. The superior sagittal sinus was completely and intensely visualized in all our patients except one, who had anterior partial agenesis and the MIP images clearly showed a dilated draining cortical vein.

In order to determine the usefulness of CE techniques for evaluating pathological conditions that involve the cerebral venous structures, it is necessary to investigate their reliability in visualizing normal intracranial dural sinuses and veins. Several studies have indicated the good visibility of small vessels using the CE 3D MRA technique since it has high signal-to-noise and contrast-to-noise ratios, and hence, even very small vessels are visible (Reichenbach et al., 1997; Özsarlak et al., 2004; Lövblad et al., 2002; Yang et al., 2002; Duran et al., 2002). This finding is supported by our results, in which 60% of cortical veins and 71% of non-dominant sinuses were of grade A.

Our study demonstrated a high visualization rate of major dural sinuses and of deep and cortical cerebral veins. The frequency of visualiza-

tion of these structures is in good agreement with that reported for DSA. The large dural sinuses, the vein of Galen, and the internal cerebral veins were completely visualized in all cases. Therefore, the absence of visualization of one of these structures with CE 3D MRA should be considered a pathological rather than normal variant. In addition, there was no evidence of venous collateral circulation in any case with a hypoplastic, or partially visualized sinus, and this represents an important observation since it permits misdiagnosis of dural sinus thrombosis to be avoided. The inferior sagittal sinus, the thalamostriate veins, and the basal veins of Rosenthal were completely or partially seen in 61%, 86%, and 90% of cases, respectively. The reported DSA rates in the literature for these structures vary between 60%-68% for the inferior sagittal sinus; 38%-86% for the thalamostriate veins, and 50%-99% for the basal veins of Rosenthal (Stein and Rosenbaum, 1974; Modic et al., 1983; Mattle et al., 1991; Wetzel et al., 1999). The variability in DSA rates could be related to the angiographic protocol used in each center. In addition, our results are comparable to those reported by Kirchhof et al. (2002) using the same sequence, and slightly better than those reported by Liang et al. (2001) using CE MP-RAGE and Farb et al. (2003) using the ATECO sequence.

The reported rates for TOF MRA are largely variable because of the imaging plane used. Our results, however, are higher than those acquired in the transverse or sagittal planes (Liauw et al., 2000; Liang et al., 2001); similar to some values (Mattle et al., 1991; Ayanzen et al., 2000; Kirchhof et al., 2002), and higher than others (Liauw et al., 2000; Farb et al., 2003) acquired in the coronal plane. In addition, in our study the distribution of transverse sinus dominance is similar to that reported by Ayanzen et al. (2000) using the TOF technique acquired in the coronal plane; the transverse sinus was found to be right, left, and codominant in 59%, 25%, and 16% of cases, respectively. In our study, these rates were 58%, 19%, and 23%, respectively, and are in excellent agreement with those reported by Modic et al. (1983) using intravenous DSA; the rates in their study were 56%, 18%, and 26%, respectively.

After reviewing the literature, we found that all MR angiographic techniques, with or without contrast enhancement, have limitations and disadvantages. We believe that currently there is no ideal method for imaging

the cerebral venous system, including conventional angiography, since all these methods may show technically related artifacts that render the interpretation ambiguous.

The main pitfalls of the technique used in the present study are that pacchionian granulation and intravenous septa could be misdiagnosed as thromboses (Özsarlak et al., 2004). Several studies (Liang et al., 2001; Kirchoff et al., 2002; Connor and Jarosz, 2002) have demonstrated that chronic thrombi may be enhanced, such that thrombosed sinuses may be reported as normal. In addition, the absence of a gold standard examination in the present study can be considered another limitation. CE 3D Turbo-flash MRA allowed complete coverage of the brain and demonstrated greater vascular detail than did other MR venography techniques, in spite of the aforementioned pitfalls.

In conclusion, the frequency of visualization of the dural sinuses and cerebral veins obtained using the CE 3D Turbo-flash MRA technique and the distribution of transverse sinus dominance are in excellent agreement with the values reported in the literature for both DSA and MRA techniques using the same or other sequences, such as MP-RAGE or ATECO. However, CE 3D Turbo-flash MRA offers the advantage of a shorter examination time.

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