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Anatomical Assessment of Cerebral Venous System by 3D phase contrast MR Venography

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Abstract
Purpose: *The purpose of the study was to know the normal anatomy and its variants and identify the imaging criteria that discriminate normal anatomical variants from thrombosis and other pathological condition. To check the accuracy of non enhanced 3D phase contrast magnetic resonance venography (3D PC-MRV) vs contrast enhanced magnetic resonance venography (CE-MRV).*
Material and Methods: *It is a descriptive type of observational study done on 192 patients who were referred for investigation of part other than brain and who had normal results of MR imaging of the brain (having no manifestations of cerebrovascular diseases) were recruited into the study. The larger cerebral veins and all sinuses, including the occipital sinuses, were assessed by using oblique sagittal non enhanced 3D PC-MR venography. Among 192 cases, The 81 cases also had CE-MRV provided study material for comparisons with non contrast MR venography.*
Results: *Hypoplastic left TS was most common anatomical variation in 31.8% (61). Hypoplastic right TS 6.25% (12), aplastic right TS one (0.52%), aplastic left TS aplastic/atretic in 3.1% (6) cases, hypoplastic right SS 6 (3.1%) and hypoplastic left SS in 25 % (49) in cases. OFG/AG was seen in 21% (42) cases. Most common variation of SSS was hypoplasia of anterior one third in 18.8% (36) and bifurcated near lambdoid suture of the cranium in 11% (21). The deep venous system is invariably consistent, except small variations in BVOR. In 76 (41.5%) of 192 cases without occipital sinuses, absent or hypoplastic TS were found. Nine patients had occipital sinuses. In seven (78%) of nine patients with occipital sinuses, absent or hypoplastic transverse sinuses were shown.*
Conclusion: *These anatomical variants and artifacts can be a potential pitfall in the MRV diagnosis of CVST, especially when there are no supportive imaging features such as brain infarcts or appropriate clinical background. Therefore, it is essential for radiologist to be familiar with MRV characteristics and anatomy so that they are not misinterpreted as CSVT. 3D PC MRV is a great option for patients with gadolinium allergy/renal insufficiency/pregnant patients can provide comparable results to CE MRV.*
Keywords: *3D phase contrast magnetic resonance venography, contrast enhanced magnetic resonance venography, superior sagittal sinus, transverse sinus, sigmoid sinus and arachnoid granulations.*

Introduction

Normal variations of the venous sinuses include aplasia and/or hypoplasia of certain segments, arachnoid granulations, flow gaps, slow flow, and in plane artifacts and the presence of embryological remnants such as a persistent falcine or occipital sinus.[1]These variations are necessary to evaluate during diagnosis and surgical management of certain neurosurgical pathologies includes CVT[2], stenosis/ occlusion[3], Idiopathic Intracranial Hypertension[4] and Dural Arteriovenous Fistula. Various modalities are available to evaluate normal cerebral venous anatomy, its variant and pathology. Digital Subtraction Angiography (DSA), CT Venography, Conventional 3D Contrast-Enhanced MR Angiography (CE-MRA), CE Time-Resolved MRA, TOF MR Angiography, 3D Phase Contrast (PC) MRV. DSA is traditionally considered as gold standard for venous studies, especially diagnosis and treatment of AVM. The invasiveness of the procedure restricts its use to the time of treatment.[5] CT Venography had radiation exposure. CE-MRA is producing high-quality angiograms, however it requires contrast media administration. CE Time-Resolved MRA is faster and new technique, provide dynamic information about blood flow in addition to the information given by static contrast-enhanced angiographic techniques.[5]TOF MR Venography had many Limitations mainly related to artifacts resulting from slow blood flow and turbulent or pulsatile flowpatterns.[5,6] Phase contrast MR venography, which uses velocity-induced phase shifts to show flowing blood is typically used to perform MR venography with contrast administration being unnecessary.[7]Recognized major advantages of PC MRV include optimized suppression of stationary background tissues (greater than TOF imaging) together with the ability to quantify flow and determine flow direction.[8]

Material and Methods

The study was conducted on a group consisting of 200 cases among which 8 cases were excluded from the study due mass lesion or operative procedure involving dural sinuses. The study was done in during the period between November 2017 and December 2018.The subjects of this study were referred to Dept. of Radio-diagnosis from OPD/IPD for MRI scan of parts other than brain having no manifestations of cerebrovascular diseases. Among 192 cases, The 81 cases also had CE-MRV, provided study material for comparisons with non-contrast MR venography. Patients with; Congenital anomaly, Manifestations of cerebrovascular disease**,** h/o brain tumor or other space occupying lesion**,** Prior brain surgery**,** Cardiac pacemakers Implanted electrodes, Metallic ear prosthesis were excluded.

MR Imaging; All MR venograms were performed at our institute using PHILIPS 1.5 TESLA ACHIEVA MRI SCANNER with standard head coil, Philips workstation and intellispace software. The MR venography protocol consisted of non-contrast 3D PC-MRV in oblique sagittal plan and employs parallel imaging with the position of saturation band at the bottom of block. The following parameters: TR 16m/s, TE 10ms, relative SNR 1.00, NSA 1.5, FOV 224mm × 168mm x 149 mm, matrix; 224 × 130 x 166 mm Acquisition voxel 01/1.28/1.8 mm PC/VENC (cm/s) 15, slice thickness -0.9mm, 220 images and time 3.42s were obtained. Additional Routine, T2WI sagittal structural MRI sequences were also performed. Those patients who came for contrast MRI parts other than brain and had normal renal function test (RFT) also underwent contrast enhanced MRV (CEMRV).Maximum intensity projections (MIPs) and multilane reformation (MPR) were created to produce an "angiographic-like" image for 3D-MR venography data set and viewed in the sagittal, transverse and coronal planes.[17] Imaging findings of the major veins and all sinuses were recorded. Any anatomic variant was also recorded. If veins could not be identified at all, it was described as not visualized. The normal variations of transverse (TS) and sigmoid sinuses (SS) were noted (symmetry, hypoplasia and aplasia or atresia). The TS calibre was measured in distal one third. When the difference between diameter of right and left TS was less than or equal to 25% it was considered normal; if more, than 25% the smaller one was called hypoplasia. If not visualized it was considered a plastic or Atretic sinus. Oval (O-FG) flow gaps have been recorded and were considered as arachnoid granulation

Statistical Analysis: Mean ± standard deviation (SD) was used to shown numeric values. Chi-square contingency analysis was used to explore the statistically significant difference of MRV variations among males/females. A difference was considered significant at a P value of less than 0.05.

Observations and Results

In our study 192 cases (105men and 87women having age range 20days to 85years) with no manifestations of cerebrovascular diseases underwent MRI scan and were analyzed for variations of cerebral venous system.

Table No1: Visualization of the Deep Venous System in192

Paired structures	Right (n/%)	Left (n/%)
Basal vein of Rosenthal	184 (95%)	188 (97%)
Internal cerebral vein	190 (99%)	192(100%)
Unpaired structures		
Inferior sagittal sinus	112(58%)	
Vein of Galen	192(100%)	
Straight sinus	191(99%)	

Table No 2: Visualization of the Superficial Venous System in 192

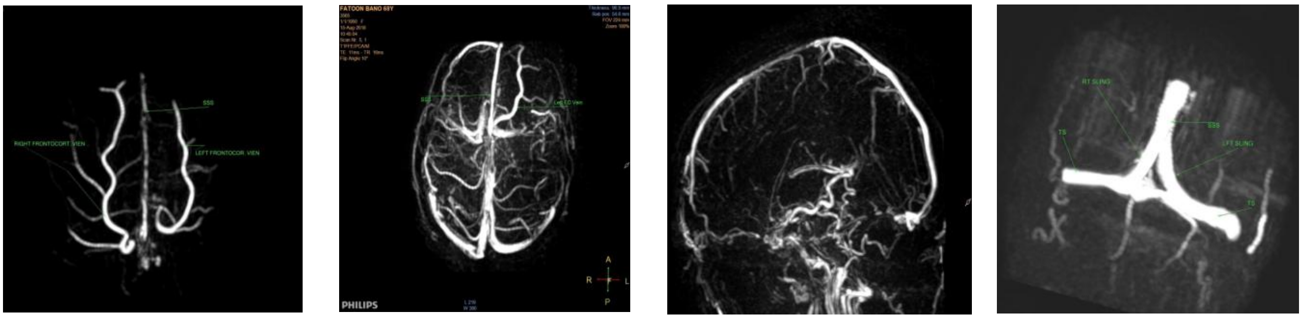
Paired structures	Right	Left
Transverse sinus	190 (99%)	185 (96%)
Sigmoid sinus	191 (99.5%)	188 (98%)
Internal jugular vein	191 (99.5%)	190 (99%)
Vein of Trolard	165 (86%)	158(82%)
Vein of Labbé	177 (92%)	174 (90%)
Superficial petrosal sinus	185 (96%)	183(95%)
Inferior petrosal sinus	187 (97%)	190(99%)
Ophthalmic vein	178(92%	171(89%)
Sphenoparietal sinus	148(77%)	138(72%)
Superficial middle cerebral vein	150 (78%)	148(77%)
Unpaired structures		
Superior sagittal sinus	192 (100%)	

Visualization of the Deep and Superficial Venous System are present in table 1and 2. The deep venous system is invariably consistent, with small variations in its anatomy. Basal vein of Rosenthal (BVOR) had showed only few variations likely join directly to vein of Galen, to straight sinus and torcular Herophili in one subject. Superficial Venous System had extreme variation. SMCVs had 4 variations in the drainage patterns. The most frequent pattern was drainage into the SPS (50%). The SPS had 3 variations in the drainage patterns. The most frequent pattern was drainage into cavernous sinus in 3/4th cases.

Table No 3: Normal variation of superior sagittal sinus (n=192)

Variation	Total=192		Male=105		Female=87		P value
Normal	128	66.7%	68	64.8%	60	69%	0.539
Anterior 1/3rdHypoplastic	36	18.8%	20	19%	16	18.4%	0.908
Split Posteriorly	21	11%	12	11.4%	9	10.3%	0.811
Middle Hypoplastic	3	1.5%	2	1.9%	1	1.1%	1.000
Posterior Hypoplastic	3	1.5%	2	1.9%	1	1.1%	1.000
Stenosed	1	0.5%	1	0.9	0	0	1.000
Total	192	100%	105	100%	87	100%	

Frequencies of variation of superior sagittal sinus (SSS) are present in table 3. Most common variation of SSS was hypoplasia of anterior one third in 18.8% cases (fig1a and 1b), second is that SSS splitposteriorly (fig1d), coursed as two separate branches and drained into the transverse sinus without forming the confluence of the sinuses in 11% cases and third is middle hypoplastic (fig1c). There is no statistically significant difference among males and females for these variations.



(a) (b) (c) (d)

Fig 1: Axial 3D PC-MRV MIP images, (A) bilateral anterior hypoplastic and (b) Left anterior hypoplastic superior sagittal sinus with parasagittal front ocortical vein.(c) Sagittal, showed middle hypoplastic superior sagittal sinus. (d) Oblique coronal, showed posteriorly split superior sagittal sinus.

Table No 4: Normal Variations of Transverse Sinuses(n=192).

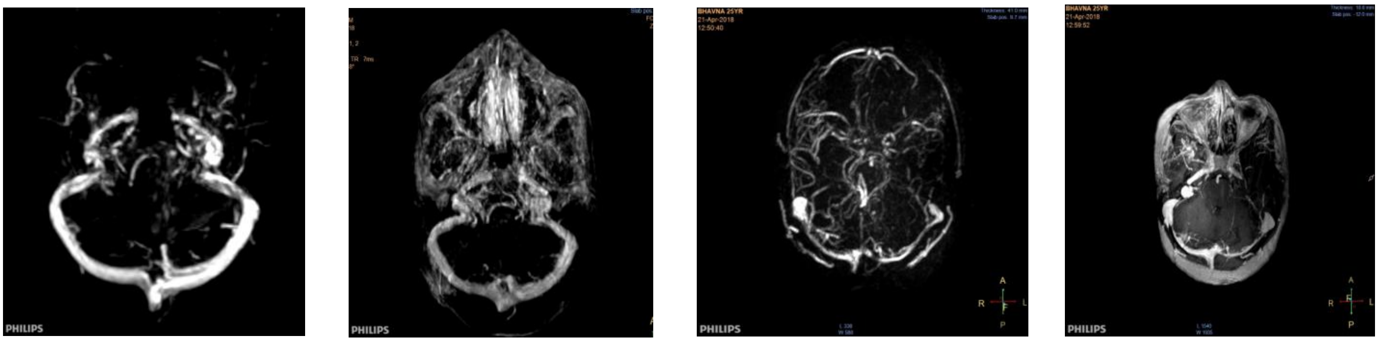
Variation	Total=192		Male=105		Female=87		P value
Symmetrical	109	56.7%	57	52%	52	59.7%	0.445(NS)
Left sided hypoplastic	61	31.8%	35	33.3%	26	29.9%	0.609(NS)
Left sided aplastic/NV	6	3.1%	4	3.8%	2	2.2%	0.691(NS)
Right sided hypoplastic	12	6.25%	7	6.7%	5	5.7%	0.793(NS)
Right sided aplastic/NV	1	0.52%	0	0	1	1.1%	0.453(NS)
B/L hypoplastic	3	1.5%	2	1.9%	1	1.1%	1.000(NS)
	192	100%	105	100%	87	100%	

Frequencies of variation of transverse sinus (TS) are present in table 4. In 56% cases b/l symmetrical TS (fig2a and 2b). Right transverse sinus was hypoplastic in6.25% (fig3c and 3d)and aplastic/atretic in 0.52% (1) cases. Ten cases of hypoplastic right TS also had CEMRV. Out of them, five cases were truly hypoplastic in both CE-MRV and PC-MRV and five discrepant cases, among which three cases showed normal caliber on contrast MRV (flow related hypoplasia) and two cases showed filling defect (thrombosed) (fig 4). Left transverse sinus was hypoplasticin31.8% (fig3a and b) and aplastic/atretic in 3.1% (6) cases. Out of the 61 cases, 26 cases had CEMRV also and it was observed that seven cases showed normal caliber and opacification (flow related hypoplasia) and19 cases are truly hypoplastic on both PC-MRV and CEMRV. This discordant in 7 cases, are attributed to inherence limitation of PCMRV of showing slow flow as hypoplastic sinus (flow related hypoplasia).The 1.5 %(3) cases had bilateral hypoplastic transverse sinuses (fig2c and d) but contrast study in two cases, which showed that hypoplastic, on both 3D PC-MRV and CEMRV.OFG/AG was seen in 21% (42) cases; located in the central and lateral part of transverse sinus, more commonly in the distal part, close to vein of Labbé.

Table No 5: Normal Variations of Sigmoid Sinuses (n=192).

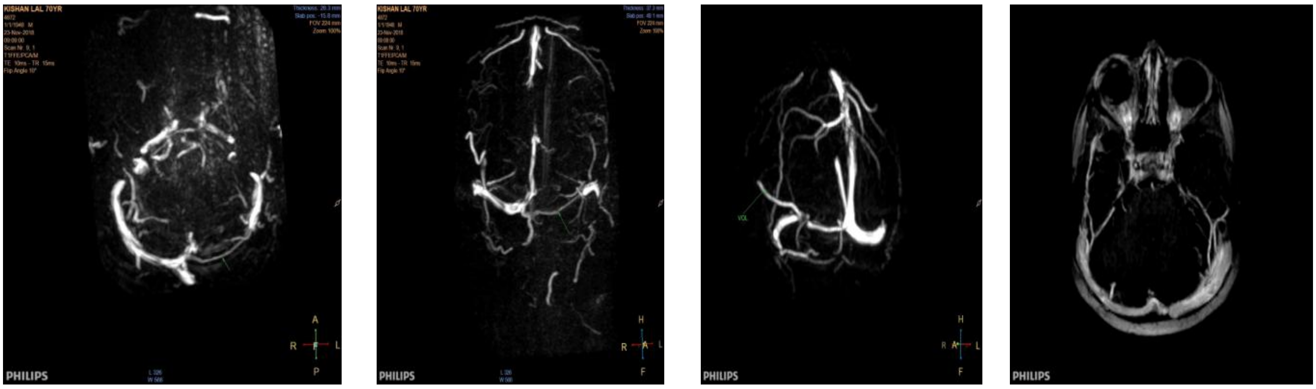
Variation	**Total=192**		**Male=105**		**Female=87**		**P value**
Symmetrical	130	67.7%	68	64.7%	62	71.2%	0.337
Left sided hypoplastic	49	25%	29	27.6%	20	23%	0.464
Left sided aplastic/NV	4	2%	3	2.8%	1	1.1%	0.628
Right sided hypoplastic	6	3.1%	4	3.8%	2	2.3%	0.691
Right sided aplastic/NV	1	0.52%	0	0	1	1.1%	0.453
B/L hypoplastic	2	1.04%	1	0.9%	1	1.1%	1.000
	192	**100%**	**105**		**87**		

Frequencies of variation of sigmoid sinus (SS) are present in table 5. In 67% cases B/L symmetrical SS (fig2a and 2b). Most common variation was hypoplastic SS (L>R). Right sigmoid sinus was aplastic/not visualized on one patient. Left sigmoid sinus was aplastic/not visualized in 4 cases. No subject with B/L aplastic sigmoid sinus. Two patients had hypoplastic bilateral sigmoid sinuses (one with patent occipital sinus, the other with prominent vertebral venous plexus). Similar to transverse sinus, sigmoid sinus was symmetrical more commonly in female than male.



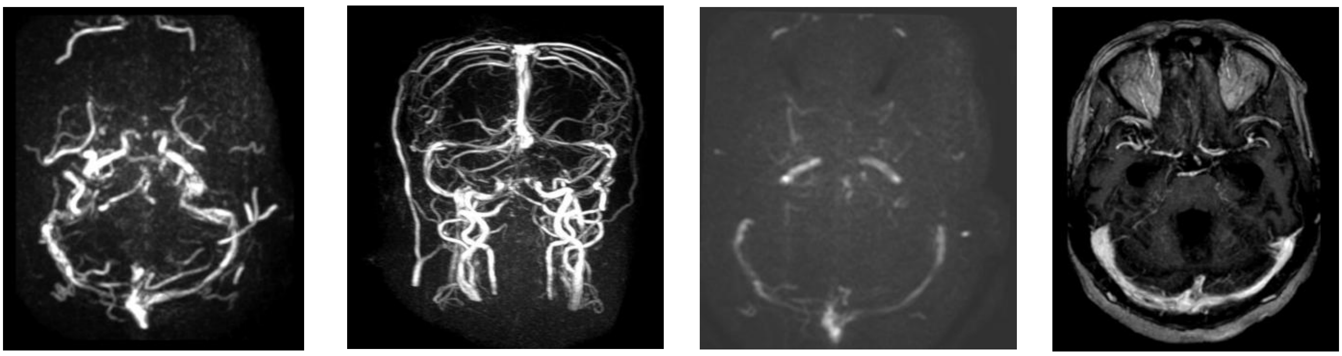
(a) (b) (c) (d)

Fig 2: Axial MIP images of b/l symmetrical transverse sinus and sigmoid sinus, (a) 3D PCV and (b) CE-MRV. Axial MIP images of b/l hypoplastic transverse sinus, (c) 3D PCV and (d) CE-MRV.



(a) (b) (c) (d)

Fig 3: 3D PC-MRV MIP images, (a) axial and (b) coronal hypoplastic left transverse sinus with occipital sinus. Hypoplastic right transverse sinus, oblique coronal 3D PC-MRV (c) and axial CE-MRV (d) MIP images.



(a) (b) (c) (d)

Fig 4:(a) Axial and (b) coronal 3D PC-MRV MIP image B/L hypoplastic transverse sinus (c) 3D PC-MRV MPR image right TS appear streaky and irregular in outline and left TS narrowed and normal in contour (d) Hypointense linear filling defect on CE-MRV MIP images of same patient suggesting chronic thrombosis with recanalisation of right transverse sinus and left transverse sinus appear normal, suggesting flow related hypoplasia on 3D PC-MRV.

Table No 6: Occipital sinus, Chi square 4.593, p value 0.041(S)

TS Status	OS Absent	OS Present
Both TS Normal	107(58.5%)	02(22.2%)
Hypoplastic or absent	76(41.5%)	07(77.8%)
Total	183(100%)	09(100%)

Occipital sinuses were present in 4.6% (9) patients. Seven (77.8%) out of nine from those patients with occipital sinuses had unilateral (mainly left)or bilateral hypoplastic or aplastic transverse sinus, whereas two (22.8%) had normal caliber transverse sinuses.

Discussion

The study was conducted to evaluate the normal anatomy of the intracranial venous system and its variation to look for any pathology and misinterpretation of its normal variation.[6] Visualization of intracranial venous system is important in certain clinical situations such as diagnosis of cortical/venous sinus thrombosis and assessment of the patency of the venous sinus lumen encased by meningioma/planning neurosurgery on brain tumours contiguous to dural sinuses.[9,10,11] In present days further interest has been raised by the observation that sinus abnormalities may be related to idiopathic intracranial hypertension[12] and glaucoma.[13] Nowadays, several different imaging techniques are available, and all have advantages and limitations. Digital subtraction angiography (DSA) has long been considered the gold standard, even though it is invasive, requiring contrast administration and radiation exposure. Comparable results may be obtained by CT venography.[14] CEMRV has replaced previous techniques and has become the favourite method of imaging the intracranial venous system. Nevertheless, the use of CM has recently been debated, as the number of reports on nephrogenic systemic fibrosis has recently increased. Moreover, one of the most frequent risk factors for venous thrombosis is pregnancy, during which CM administration is unacceptable. For this reason, non-enhanced sequences are preferable. In our study a 3D PC-MRV, in 10degree oblique sagittal acquisition is performed. The 3D PC-MRV technique has better background suppression for venous sinuses and large cortical veins than 3D TOF and CE MRV.[15] So a simple and short 3D PC-MRV protocol may be useful in clinical daily life to better investigate suspected structural or flow venous abnormalities with accuracy, especially for a number of clinical situations in which the patient cannot undergo contrast administration.[5] Deep venous system did not show variation in its anatomy except BVOR and Straight sinus. Such observation was also made by Uddin et al.[16] Most of the anatomical variations are seen in superficial venous system. SSS was visualized in all cases. TS were visualized in ~97% cases and SS were visualized in ~99% cases. It was observed that VOT and VOL were visualised bilaterally at least in 82% and 89% cases respectively. Hence in case they are not visualised bilaterally there is only a 9-19% chance of being normal variations. In such cases and other sign of cortical venous thrombosis suggesting sinus thrombosis should be cautious looked for. The most frequent pattern was drainage of SMCV is into the SPS (50%).The most frequent pattern was drainage of SPS is into cavernous sinus (74%). Such observation was also made by Chung J.I. et al.[17]Anterior third hypoplastic SSS was seen in 18.8 % in our study. San Millán Ruíz D.et al[18] reported HP-ATS in 21% cases, as they used CT venography in their study. The distinction between hypoplastic rostral SSS and thrombosis of the anterior third of the SSS relies on the demonstration of prominent bilateral superior frontal veins that follow a parasagittal course to SSS.The 11% cases demonstrated that the SSS bifurcated near the lambdoid suture of the cranium. OFG or AGs are reported in 41.7% cases in our study, predominantly middle and posterior SSS. Our study showed that symmetrical TS were in 57%, left TS was hypoplasticin 32% and right TS was hypoplastic in 6%. Our results are similar to Goyal et al[19] who reported symmetrical TS in 66.9%, hypoplastic left TS in 21.3% and hypoplastic right TS in 5.5%. However Alper et al[20] reported that symmetrical TS in 31%, hypoplastic and aplastic TS in 69%. The interpretations are discordant with our study because they used TOF venography, which overestimate hypoplastic TS due to signal drop out; slow flow in TOF is more comparable to PCMRV. In our study we found Right TS aplastic/atretic in 0.52% (1) cases and left TS aplastic/atretic in 3.1% (6) cases. Durgun Bet al[21]did an angiographic study in which the cumulative prevalence of aplasia was 2.63% (2.1% in left and 0.53% in right).In 81 cases it was possible to compare PCMRV and CEMRV (which was considered as gold standard) and it was observed that almost 84% cases showed that concordant visualization of TS (superficial venous system). In only 16% of the cases was discordance in findings of PCMRV and CEMRV. Among them, 10 normal TS were interpreted as hypoplastic, one hypoplastic sinus was interpreted as aplastic and two thrombosed sinuses were interpreted as hypoplastic. Hence it was considered that the only major disadvantage of PCMRV is overestimation of hypoplastic sinus in a small amount of cases. In our study were two such patients who had both CEMRV and PCMRV where TS thrombosis (on CEMRV) was interpreted as hypoplastic sinus on MIP images of PCMRV. On CEMRV linear streaky filling defects and irregular outline were seen, which indicated chronic sinus thrombosis with recanalisation rather than hypoplastic sinus. These cases were again reviewed on PCMRV and it was seen that MPR imaging with varying slice thickness was better in regard of showing filling defects and differentiating from hypoplastic sinus. Our study showed that accuracy in PCMRV can be increased by reviewing the MPR images along with MIP images. The conditions in which absence of unilateral or bilateral lateral sinuses is seen with tortuous vertebral venous plexus, a too good ISS or too enlarged extra cranial veins indicate sinus thrombosis rather than anatomical variation of atretic sinus. From there we can comment that the sinus is thrombosed and not an anatomical variance on the basis of non contrast 3D-PC MRV, especially on MPR images with varying slab thickness and it is not previously reported. The oval flow gaps (O-FG) were seen in 21% cases. Their location in the lateral part of the TS in correspondence with a Labbé vein excludes partial sinus thrombosis but may be suspicious of partial thrombus when found in the medial part of TS.[22]The 67.7% cases had symmetrical sigmoid sinuses (SS).Right SS was hypoplastic in 3.1% and left SS was hypoplastic in 25% cases. Right SS was aplastic/not visualized for one patient. Left SS was aplastic/not visualized in 2% cases and there wasno subject with B/L aplastic sigmoid sinus. Two patients had hypoplastic bilateral sigmoid sinuses (one with patent occipital sinus other with prominent vertebral venous plexus). Our results are similar to Goyal et al[23]; the differences were due to different MRI technique and ethnic group populations. In our study, occipital sinuses were present in 4.6% (9) patients. It is less as compared to a previous study done by Widjaja E. et al,[24] who reported 18% incidence and isdue to a different age group (median age, 5 years). When B/L TS is normal then occipital sinus (OS) is present only in 1.8% cases and TS is hypoplastic or atretic then OS is seen in 8.4 % cases. This is supporting the finding that OS remain patent if TS is hypoplastic to maintain drainage.

Conclusion

This study emphasizing the clinical significance of normal intracranial cerebral drainage variations in various diagnostic and neuro-interventional procedures. These variants and artifacts can be a potential pitfall in the MRV diagnosis of CVST, especially when there are no supportive imaging features such as brain infarcts or appropriate clinical background. Therefore, it is essential for radiologist to be familiar with MRV characteristics and anatomy so that they are not misinterpreted as CSVT. 3D PC MRV is a great option for patients with gadolinium allergy/renal insufficiency/pregnant patients can provide comparable results to CE MRV. Limitation of our study (1) contrast study was not done in all patients, (2) comparison with gold standard conventional angiography was not present in our study, (3) since all our patients did not have any complain related to cranium and had come for study other than cranium, it was assume that acute and chronic thrombosis was not present in most of patients except for three patients which had shown obvious imaging characteristic of thrombosis on contrast enhanced study.

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