Usefulness of 4D-CTA in the Detection of Cerebral Dural Sinus Occlusion or Stenosis with Collateral Pathways

Y. ONO¹, K. ABE¹, K. SUZUKI¹, H. IIMURA¹, S. SAKAI¹, S. UCHIYAMA², Y. OKADA³

¹Department of the Diagnostic Imaging and Nuclear Medicine, ²Department of Neurology, ³Department of Neurosurgery, Tokyo Women's Medical University; Tokyo, Shinjuku-ku, Japan

Key words: 4D-CTA, cerebral dural sinus, sinus occlusion, sinus stenosis, venous thrombosis

SUMMARY – *In time-resolved CT angiography (4D-CTA), it is of substantial merit to detect the veins and sinuses of the whole brain with the simultaneous demonstration of the natural drainage flow in order to find occlusion or stenosis of the dural sinuses with collateral pathways. As preoperative information for patients with brain tumors, it is important to detect feeding arteries, incidentally found aneurysms or other vascular lesions, and to detect patency of the dural sinuses and the important cortical veins, whether they are compressed by tumors or not. On the other hand, cerebral venous thrombosis (CVT) may occur in patients due to various causes, which has not been unusual in recent years. For patients with acute symptomatic or chronic non-symptomatic CVT, identification of dural sinus occlusion (DSO) or dural sinus stenosis (DSS) and compensatory collateral pathways is necessary for suitable thrombolytic therapy or careful investigation to avoid further CVT. This study reviews our experiences in 116 cases of 4D-CTA for 90 patients with brain tumors and 26 other patients including 11 with arteriovenous malformation, and four with acute CVT and other conditions. 4D-CTA presented DSO/DSS with compensatory venous collateral pathways, which was helpful to detect the severity of the venous abnormality, and see whether it was compressed by brain tumors, or due to other causes in patients with symptomatic or non-symptomatic CVT. 4D-CTA is a useful non-invasive diagnostic tool to detect cerebral venous abnormalities as an alternative to DSA.*

Introduction

Time-resolved fourth dimensional CT angiography (4D-CTA) with a 320-row area detector shows an accurate opacification of the main arteries and its usefulness has already been reported to detect cerebral vascular lesions and tumors ¹⁻⁶.

However there is little information on the details of the peripheral branches, perforating arteries and capillaries which can be misinterpreted, mainly due to the superimposition of the whole brain vessels and prolonged intravenous contrast material administration. Meanwhile, 4D-CTA has the substantial merit of detecting veins and sinuses of the whole brain with simultaneous detection of the natural drainage flow, in order to find occlusion or stenosis of the dural sinuses with collateral path-

ways. Anatomical registration of the right and left-sided cortical veins is not as complicated as it is for the peripheral arteries and capillaries, which can mostly be resolved by oblique views.

As preoperative information for patients with brain tumors, it is important to detect feeding arteries, incidental aneurysms or other vascular abnormalities, and to detect patency of the dural sinuses and the important cortical veins, whether they are stenosed or occluded by tumors, or by other causes.

Cerebral venous thrombosis (CVT) ^{7,8} may occur in patients due to various causes and has not been unusual in recent years. For patients with acute symptomatic CVT, or chronic non-symptomatic CVT, dural sinus occlusion (DSO) or stenosis (DSS) and compensatory collateral pathways are necessary for the identification of definitive

Table 1 Results of 4D-CTA.

Cases			4D-CTA			
			Arterial occlusion	Aneurysm	Feeding arteries	DSO/DSS
Brain tumors	Glioma	49	0	0	0	4
	Meningioma	26	0	3	20	6
	Acoustic schwannoma	5	0	0	0	1
	Metastases	4	0	0	0	1
	Pituitary adenoma	1	0	0	0	1
Vascular diseases	Other tumors	5	0	0	0	0
	AVM	11	0	0	8	0
	Acute CVT	4	0	0	0	4
	Others	11	0	1	0	6
Total		116	0	4	28	23

information on CVT. Moreover, collateral pathway detection is necessary for suitable therapy or careful investigation to avoid further CVT.

This study reviews our experiences in 116 cases of 4D-CTA for 90 patients with brain tumors and 26 other patients including 11 with arteriovenous malformation (AVM), and four with acute CVT and other conditions.

The purpose of this study is to evaluate the usefulness of the cerebral 4D-CTA, especially for detection of DSO/DSS with collateral venous pathways, to be a non-invasive diagnostic tool alternative to DSA.

Patients and Methods

4D-CTA studies in 116 patients from May 2012 to February 2013 were reviewed. The patients were 41 males and 75 females, with an age range of 15-89 years old (mean age was 47). All cases were examined by CT and/or MRI before 4D-CTA. Ninety patients had brain tumors (49 gliomas, 26 meningiomas, five acoustic schwannomas, four metastases, one pituitary adenoma and five other tumors; three craniopharyngiomas, one epidermoid, and one Langerhans histiocytosis), 11 patients with arteriovenous malformations (involving four cases for follow-up study after gamma knife radiosurgery), four patients with active CDST and another 11 patients (two cavernous angiomas, two hypertension, one repeated heat stroke, one embolized cerebral dural AVF, one old subcortical hemorrhage after delivery, one suspicion of brain tumor, one vertigo, one giant aneurysm, and one for exclusion of AVM).

4D-CTA was performed by a 320 row detector CT (Aquilion One, Toshiba) using 0.6-0.8ml/kg of contrast medium, for a total amount of 40-50 ml, injected by 4 ml/s with a washout of 20 ml of saline. Exposure time for the 4D-CTA was 20-30 seconds with 20 shots in routine study, and exposure time was prolonged to 35-40 seconds, when circulation was evidently delayed. Antero-posterior, lateral, right- and left-anterior oblique serial images were reconstructed routinely. 3D-CTA volume rendering reconstruction was made for the each arterial and venous phases (CT Venography: CTV). 3D-CTA, CTV were fused with the enhanced tumor or AVM nidus on the source images for guidance of neurosurgery or radiosurgery.

4D-CTA images were analyzed by two experienced neuroradiologists to find angiographic abnormalities in the arterial to the late venous phase, with the points of arterial occlusion, aneurysms or dissection, feeding arteries for the tumors/AVM/AVF, the cortical and deep veins, and contour/flow direction/speed of the dural sinuses with tributaries. For differentiation of normal variations of the cerebral dural sinuses, contour and drainage pattern of the dural sinuses and tributaries were also analyzed in the 42 patients with gliomas, excluding three patients with DSO and four patients with recurrent gliomas.

Results

The total findings of the cases are presented in Table 1. There was no case with arterial occlusion. Small aneurysms were detected in

Figure 1 Case 1. Glioma Grade 3 in the right fronto-parietal lobes. A) T1-weighted image. High intensity of the left internal jugular vein with a small low intensity area inside. B) T2-weighted image. Glioma in the left frontal-parietal lobes. Antero-posterior (C), right anterior oblique (D), left anterior oblique (E) views of 4D-CTA in venous phase. Stenosis of the left transverse sinus draining into the external jugular vein (arrowhead). Occlusion of the left sigmoid sinus and the internal jugular vein with hypertrophied tributaries of the occipital sinuses (arrow).

three patients with meningiomas at the supraclinoid portion of the internal carotid arteries. One patient underwent 4D-CTA as a follow-up study of the thrombosed dissecting giant aneurysm of the right vertebral artery, and dissection proved there was no delay in arterial flow. With respect to the feeding arteries of the tumors, hypertrophy of the middle meningeal artery was visible in 20 meningiomas. In 11 patients with AVM, seven preoperative patients and one patient treated by gamma knife radiosurgery (GKR) a year before, presented feeding arteries, nidus and draining veins. In the other three cases treated by GKR more than five years ago, no feeding arteries or abnormal venous drainage was detected.

There were 23 patients with DSO/DSS (Table 2). In the patients with gliomas, DSO was

found in Cases 1/2/3, which was not related to the tumors (Case 1=Figure 1). Case 4 with recurrent glioma presented DSS and a slow flow of the superior sagittal sinus (SSS). These four cases presented developed collateral venous channels. In the patients with meningiomas (Cases 5-10), DSO was found in Cases 5/6/7. Case 5 with cavernous to tentorial meningioma presented severe compression of the cavernous sinus to be occlusion. Case 6 with right tentorial meningioma presented occlusion of the contralateral transverse sinus unrelated to the tumor. Case 7 with recurrent meningioma showed occlusion of the right sigmoid sinus, at the site of previous craniotomy. The other three patients (Case 8/9/10) presented DSS by direct compression of the meningiomas (Case 8 =Figure 2). All six patients under study developed

Table 2 Cases with dural sinus occlusion (DSO), dural sinus stenosis (DSS) or cerebral venous thrombosis (CVT).

Case	Age	Sex	CT/MR/clinical/ pathological	DSO	DSS	Main collateral routes	Final diagnosis
Gliomas	1	50	M	G3 r-fronto-parietal	l-sigmoid S to IJV	occipital S, tributaries, basal plexus	CVT incidental
	2	25	F	G4 vermis-medulla	l-sigmoid S to IJV	sup. petosal S to occipital S emissary V	CVT incidental
	3	63	M	G4 r-fronto-temporal	l-sigmoid S to IJV	tributaries, occipital S	CVT incidental
	4	53	M	G3 recurrence r-parieto-occipital		irregular stenosis of SSS, slowing	DSS post craniotomy
Meningiomas	5	39	F	l-cavernous-tentorial	l-cavernous S	basal plexus to r-cavernous S sup.petrosal S, sigmoid S	DSO by tumor
	6	58	F	r-tentorial	l-transverse S to sigmoid S	tributaries to bil.sup.petrosal S l-emissary V	CVT incidental
	7	71	F	recurrence, r-fronto-temporal convexity	r-sigmoid S	tributaries of occipital S, basal plexus	DSO post craniotomy
	8	40	M	l-parasagittal convexity		stenosis of SSS, cortical vein	DSS by tumor
	9	55	F	falx-l-deep parietal		stenosis of straight S to l-transverse S slowing	DSS by tumor
	10	48	M	l-clivus-petrosal		stenosis of l-transverse S to sigmoid S	DSS by tumor
Other tumors	11	61	F	pituitary adenoma	l-cavernous S	r-cavernous S, basal plexus to l-sup.petrosal S	DSO by tumor
	12	44	M	r-aoustic schwannoma		r-transverse S, tributaries of r-sigmoid S, l-transverse S	CVT incidental
	13	58	F	r-parieto-occipital metastasis		straight S to l-transverse S	CVT incidental
CDST	14	49	F	subconjunctival hemorrhage, small ICH	parieto-occipital SSS	r-cavernous S, bil. V Labbe sphenoparietal S early filling	CVT acute
	15	65	F	subcortical ICH	SSS, r-transverse S	cortical veins, bil. spheno-parietal S	CVT acute
	16	62	F	severe headache, tinnitus		irregular stenosis of l-sigmoid S-IJV, slowing	CVT acute
	17	60	F	severe headache		stenosis: l-transverse S-IJV, slowing	CVT acute
Other CVD	18	47	M	repeated heat strokes in 4 yrs	r-transverse S	tributaries to l sigmoid S	CVT chronic
	19	35	F	l-parietal ICH after delivery, 1 yr ago		defects in straight S to confluence	CVT chronic
	20	48	M	l-frontal tumor suspected		defects in l-transverse S to straight S	CVT chronic
	21	89	M	hypertension	l-cavernous S	basal plexus to r-cavernous S l-superior orbital V	CVT incidental
	22	44	F	vertigo	r-transverse S to IJV	r-temporal cortical V, basal plexus	CVT incidental
	23	54	F	dural AVF post embolization 4 month	l-transverse S	tributaries to l-sigmoid S slowing	DSO post embolization

SSS: superior sagittal sinus; IJV: internal jugular vein; AVF: arteriovenous fistula; ICH: intracerebral hemorrhage; CVD: cerebrovascular disease; S: sinus; V: vein(s); r: right; l: left; sup: superior; bil: bilateral; G: grade (of gliomas). Cases 1, 8, 14 are demonstrated in the figures.

Figure 2 Case 8. Left parasagittal-convexity meningioma, A,B) Gd-T1-weighted images. Left parietal parasagittal-convexity meningioma, compressing the SSS. C,D) Arterial phase of 4D-CTA. Prominent hypertrophy of the middle meningeal, superficial temporal and occipital arteries on both sides, presenting tumor stain. E,F) Venous phase of the 4D-CTA. Stenosis of the SSS (short arrow) and cortical veins (arrow) by tumor compression. Hypertrophy of the other cortical veins around the tumor. G,H) Fusion image of the enhanced tumor, volume rendering images of the arteries and veins.

venous collateral circulation and hypertrophied tributaries of the dural sinuses involved. In the other patients with brain tumors, DSO was detected in Case 11 with a large pituitary adenoma compressing the cavernous sinus to be occlusion. DSS was detected in Case 12 with acoustic schwannoma and Case 13 with metastasis, which was unrelated to the tumors. The collateral venous channels were also developed in these cases.

In four patients, Cases 14-17 with severe headache or intracerebral hemorrhage, there were suspected to be CDST by CT/MRI. Case 14 (Figure 3) showed abnormal vascularity in the right cavernous sinus on the T2-weighted image. On the 4D-CTA, the right internal carotid artery was intact and early filling of the right cavernous sinuses and vein of Labbé on each side was detected. There was occlusion of the posterior third of the SSS with an irregularly

Figure 3 Case 14. Active sinus thrombosis with a small arteriovenous fistula around the cavernous sinuses. A) T2-weighted image. Abnormal vascular flow void (arrow) in the right cavernous sinus. B) FLAIR image. High intensity in the SSS and at the cortex of the right fronto-parietal and left frontal lobes. C,D) Arterial phase of 4D-CTA. Early opacification of the right cavernous sinuses draining into the bilateral veins of Labbé (small arrowheads). E-H) AP, right anterior oblique, left anterior oblique, lateral views in the venous phase of 4D-CTA. Irregular defects in the posterior half of SSS the confluence, right transverse and straight sinuses (arrows) with prominently hypertrophied sphenoparietal sinuses and the tributaries of the involved sinuses.

shaped, long defect inside. There were also remarkably hypertrophied tributaries of the SSS and the sphenoparietal sinuses. Case 15 with subcortical hematoma in the right frontoparietal lobes showed a large defect in the posterior parietal SSS to the right transverse sinus with remarkably hypertrophied cortical veins and the sphenoparietal sinuses on both sides. Cases 16 and 17 presented stenosis in the transverse to sigmoid sinuses and the internal

jugular veins with hypertrophied tributaries of these sinuses with prominently delayed flow.

In the other six patients (Cases 18-23), Case 18 with a history of repeated heat strokes presented DSO. Case 19 with a history of subcortical hemorrhage after childbirth one year ago, showed stenosis of the straight sinus to the confluence with hypertrophied tributaries at the confluence. Case 20 with suspicion of a glioma in the left frontal lobe on CT/MR,

Table 3 Contour and drainage pattern of the cerebral dural sinuses in 42 cases with gliomas.

<i>Suspicion of anomaly</i>	<i>SSS</i>	<i>Confluence</i>	<i>Transverse sinus</i>	<i>Sigmoid sinus</i>	<i>Straight sinus</i>	<i>Total</i>
Hypoplasty			20 (R: 5 L: 15)			20
Arachnoid granules	2	1	12		3	18
Fenestration duplication	2	11	5			18
Varix-like dilatation				2		2
Deviation of confluence		2				2
No remarkable findings						6

presented irregularly shaped defects in the left transverse and straight sinuses with hypertrophied tributaries. Hypertrophic cortical veins were also recognized at the left frontal lobe, which were compatible with enhanced vessels at the left frontal cortex on MRI.

Case 21 with hypertension and Case 22 with vertigo presented DSO. Case 23 with status post-embolization of the dural AVF, presented occlusion of the left transverse sinus at the site of intervention and no residual AVF was detected.

Patients (Case 18, 19, 20) with DSO/DSS and a history compatible with CVT were diagnosed to have chronic CVT, and DSO/DSS unrelated to the primary diseases. Other cases (Case 1, 2, 3, 6, 12, 13, 21, 22) were diagnosed to be incidental.

Contour and drainage pattern of the dural sinuses are listed in Table 3 in the 42 patients with gliomas. There were six patients with unremarkable findings. Twenty patients presented asymmetry of the transverse sinuses (five patients with dominance on the right, 15 patients with dominance on the left). Arachnoid granules were detected in 18 patients with round, semicircular or oval defects, which were solitary or multiple inside or at the periphery of the dural sinuses. Twelve patients presented arachnoid granules in the transverse sinuses, three patients presented them in the straight sinus, and the granules are recognized in the SSS in one patient, and at the confluence of one patient. Fenestration or duplication of the dural sinuses was detected at the confluence in 11 patients, at the transverse sinuses in five patients and at the posterior SSS in two patients. Varix-like dilatation of the sigmoid sinus was detected in two patients. Deviation of the confluence was recognized in two patients with a prominent shift of the SSS and the straight sinus to the right. Single anomaly of the dural sinuses, or coincidental anomalies were detected in one patient.

Discussion

With tremendous CT technological progress in recent years, 3D-CTA has already become one of the standard imaging tools for the cerebral arteries. Utilizing a 320-row area detector CT, it has become capable to show the serial subtraction angiography called 4D-CTA, 3D-CT-DSA or dynamic 4D-CTA. The usefulness of 4D-CTA is reported for cerebral vascular diseases¹⁻⁵, such as aneurysms, dural AVF, AVM, and spinal AVM.

As a 320-row area detector CT has been introduced to our hospital, we have begun 4D-CTA examinations involving patients with brain tumors to use it as safe non-invasive cerebral angiography to detect preoperative information. As the cases progressed, it was found that 4D-CTA showed accurate demonstration of the main arteries, and more detailed information on the venous systems became available.

In comparison with DSA, which has been the golden standard to detect detailed information of the cerebral vessels, 4D-CTA presents partially limited information on the peripheral and perforating arteries and the capillaries due to superimposition of the whole brain circulation, special and contrast resolution of CT, and prolonged intravenous contrast medium administration. With developed diagnostic procedures in MRI, detailed angiographic information on the DSA, such as perforating arteries, subependymal veins, deep medullary veins, etc. can be substituted by MRI and may not be expected on the 4D-CTA.

The arteries on the 4D-CTA are mostly identified in the early arterial phase on the AP and oblique views to avoid misregistration of each vessel in the mixed opacification of the capillaries and early opacified veins. Vascular abnormality in the capillary phase is the most difficult to identify because of unclear separation of the arteries and the veins due to intravenous contrast medium administration.

Figure 4 Anomalies of the cerebral dural sinuses. A) Asymmetric transverse sinuses, hypoplasia on the left. B) Fenestration at the confluence. C) Deviation of the confluence to the right with fenestration and lobulated defects of the arachnoid granules (arrow). D-F) Arachnoid granules at the superior sagittal, straight and left transverse sinuses and the confluence (arrows) of a patient. G) Diverticulum-like dilatation of the sigmoid sinus. H) Fenestration of the SSS (arrow).

The main cortical veins (the superficial sylvian, Trolard's and Labbé's veins) and the deep veins (thalamostriate, basal, internal cerebral, galenic veins) were identified in most cases with drainage into the dural sinuses. Other subependymal veins were observed on the lateral view, but difficult to identify on the AP and oblique views. Intravenous contrast medium administration maintains a high concentration

in the veins and dural sinuses on the 4D-CTA to show precise cerebral venous drainage without effects from selective catheterization, injection pressure of contrast medium, and laminar flow via the circle of Willis or from the contralateral vertebral artery.

In our study, there was no patient with arterial occlusion so there was no experience to detect the leptomeningeal collateral circula-

tion. In the cases with AVM, demonstration of the main feeding arteries, nidus and draining veins were excellent in larger AVM as reported^{2,4,6}. Around and inside the AVM nidus, each vascular structure was unclear and small vessels may not be demonstrated or a small nidus may be underestimated⁵. The information on AVM was considered insufficient for embolization or surgery, but for identification of AVM in the routine study or for follow-up study after GKR or embolization, 4D-CTA was useful to show non-treated AVM or residual abnormal vessels.

Incidental aneurysms were found in the three cases with brain tumors, in the one case with almost thrombosed aneurysm and dissection of the vertebral artery, the orifice of the aneurysm and slight dissection of the vertebral artery were detected maintaining normal flow speed of the artery. Detection of arterial flow is important information only detected by DSA and 4D-CTA. For meningiomas, hypertrophy of the middle meningeal arteries was clearly detected. The meningo-hypophyseal trunks could not be identified even in patients with tentorial meningiomas. Demonstration of the ophthalmic arteries depended on the patients even with or without meningiomas at the frontal base or falx. For gliomas or other tumors, the feeding arteries were hardly visible. On the fusion images of the volume rendering 3D-CTA, 3D-CTV and enhanced tumor on the source images, the relation between the tumor and the arteries/veins/sinuses was well-identified and helpful for the neurosurgical procedure² and GKR.

For identification of DSO/DSS, differentiation from venous anomalies was most important. DSO is not difficult to identify on 4D-CTA with hypertrophied tributaries or prominent pathways to the other sinuses. Diagnosis for DSS must be carefully differentiated from various venous anomalies⁹⁻¹³. Images of the dural sinuses were analyzed in 42 patients with gliomas who were uneventful for CVT. Anomalies of the dural sinuses were detected as hypoplasia, arachnoid granules, fenestration or duplication, anomalous contour or deviation. Asymmetry of the transverse sinuses was frequent, with left side dominance in two thirds of the patients, though the dominant side varied in the previous reports⁹⁻¹³. Arachnoid granules were also often visualized to be round, oval or lobulated defects¹³ in side of the sinuses, or at the wall of the sinuses to be differentiated from compression and stenosis by tumors.

In our cases stenosis of the dural sinuses was detected with irregular narrowing of the sinuses or relatively long or irregular defects in the sinuses different from the contour of the arachnoid granules with prominently developed collateral venous channels. Delayed flow of the narrowed sinuses was noted in some patients, but not always.

DSO/DSS was found in the 23 patients. There were 13 patients with brain tumors. Four patients with meningiomas and one patient with a pituitary adenoma presented DSO/DSS by direct compression of the dural sinuses by the tumor. Six patients with brain tumors, without compression of the dural sinuses, previous history or symptoms, presented DSO/DSS, which was considered to be incidental CVT. In the two patients with previous craniotomy, DSO and DSS were detected close to the site of the operated area, possibly caused by a previous operative procedure.

Nevertheless, if the dural sinus is compressed but patent, the sinus must be spared in neurosurgery to avoid venous congestion of the brain parenchyma. When the sinuses are completely occluded by the tumor and the collateral pathways are developed, these collateral routes must be spared. Zhen, et al.¹⁴ reported the importance of preoperative evaluation of the venous systems for parasagittal meningiomas, and Tiglier et al.¹⁵ also reported the importance of collateral venous flow and surgical procedures for parasagittal meningiomas.

This also applies to incidental DSO/DSS for patients with brain tumors or other malignant tumors as it is generally known that coagulation/fibrinolysis activation^{16,17} presents deep venous thrombosis. The incidence of thromboembolism is believed to be higher in patients with brain tumors than in those with systemic disease¹⁸. Detection of incidental CVT before surgery is important for careful management or for preventive thrombolytic therapy to avoid exacerbation of CVT after neurosurgery.

Four of our patients had clinical symptoms compatible with active CVT, and thrombus in the dural sinuses or parenchymal hemorrhage was detected on CT/MRI. 4D-CTA presented irregular defects in the dural sinuses, prominently hypertrophied cortical veins and tributaries of the involved dural sinuses and markedly developed sphenoparietal sinuses in the these patients. In one patient (Case 14=Figure 3) with bilateral subconjunctival bleeding and multiple subcortical hemorrhage, there were abnormally small vessels in the right cavern-

ous sinus on the T2-weighted image. In 4D-CTA, early opacification of the right cavernous sinus with hypertrophied vein of Labbé on each side was detected, compatible with dural AVF around the cavernous sinuses. This patient presented occlusion of the posterior third of the SSS and the right transverse sinus with hypertrophied collateral pathways. Carotid cavernous fistula or aneurysm of the internal carotid artery was ruled out.

Three patients with repeated heat stroke, old subcortical hemorrhage, and convulsive attack presented DSO/DSS. The last case was suspected to have a glioma on CT and MRI after convulsion. But the lesion disappeared when the patient underwent 4D-CTA after two months. These three cases presented developed tributaries of the sinuses and cortical veins, but was not as remarkable as the patients with acute CVT. One case with hypertension and the other with vertigo presented DSO, found incidentally. Case 23 with a history of embolization of cerebral dural AVF presented DSO of the left transverse due to previous intervention and no recurrence of AVF on the 4D-CTA.

Active CVT occurs due to various causes. It is not unusual^{7,8}, and must be diagnosed in an

early stage to avoid a catastrophic outcome. On routine time-of-flight MRA¹⁹ to rule out vascular lesions, it is also not unusual to find demonstration of the dural sinuses with high intensity as noted in Case 22, which is possibly coagula in the dural sinuses or early venous/sinus flow due to dural AVF. 4D-CTA is recommended for these patients to demonstrate its causes.

In the all cases with DSO/DSS, D-Dimer value was elevated, prominently in the active cases (more than 10.0) and less remarkable in the chronic cases (less than 3.0). The D-Dimer value was helpful for non-symptomatic patients with high intensity dural sinuses on MRA, to decide the indication for 4D-CTA.

Conclusion

With these experiences, 4D-CTA proved a useful diagnostic tool for cerebrovascular abnormality, especially for the identification of DSO/DSS due to direct compression by brain tumors, active CVT and chronic/incidental CVT. 4D-CTA is a useful non-invasive alternative to DSA to detect cerebral venous abnormalities.

References

- 1 Hayakawa M, Katada K, Anno H, et al. CT Angiography with electrocardiographically gated reconstruction for visualizing pulsation of intracranial aneurysms: identification of aneurysmal protuberance presumably associated with wall thinning. *Am J Neuroradiol.* 2005; 26 (6): 1366-1369.
- 2 Kinoshita T. [Progress in novel imaging with 320 row area detector CT]. [Article in Japanese]. *Innervision.* 2011; 26: 98-101.
- 3 Inoue S, Hosoda K, Fujita A, et al. Diagnostic imaging of cerebrovascular disease on multi-detector row computed tomography (MDCT). (in Japanese). *Brain Nerve.* 2011; 63 (9): 923-932.
- 4 Willems PW, Brouwer PA, Barfett JJ, et al. Detection and classification of cranial dural arteriovenous fistulas using 4D-CT angiography: Initial experience. *Am J Neuroradiol* 2011; 32 (1): 49-53.
- 5 Willems PW, Taeshineetanakul P, Schenk B, et al. The use of 4D-CTA in the diagnostic work up of brain arteriovenous malformations. *Neuroradiology.* 2012; 54 (2): 123-131.
- 6 Yamaguchi S, Takeda M, Mituhara T, et al. Application of 4D-CTA using 320-row area detector computed tomography on spinal arteriovenous fistulas: initial experience. *Neurosurg Rev.* 2013; 36 (2): 289-296.
- 7 Saposnik G, Barinagarrementeria F, Brown RD Jr, et al. Diagnosis and management of cerebral venous thrombosis: a statement for healthcare professions from the American Heart Association/American Stroke Association. *Stroke.* 2011; 42 (4): 1158-1192.
- 8 Ferro JM. Cerebral venous thrombosis. *J Neuroradiol.* 2002; 29 (4): 231-239.
- 9 Surendrababu NR, Subathira, Livingstone RS. Variations in the cerebral venous anatomy and pitfalls in the diagnosis of cerebral venous sinus thrombosis: low field MR experience. *Indian J Med Sci.* 2006; 60 (4): 135-142.
- 10 Ayanzen RH, Bird CR, Keller PJ, et al. Cerebral MR venography: normal anatomy and potential diagnostic pitfalls. *Am J Neuroradiol.* 2000; 21 (1): 74-78.
- 11 Agid R, Shelef I, Scott JN, et al. Imaging of the intracranial venous system. *Neurologist.* 2008; 14 (1): 12-22.
- 12 Fukusumu A, Okudera T, Takahashi S, et al. Anatomical evaluation of the dural sinuses in the region of the torcular herophili using three dimensional CT venography. *Acad Radiol.* 2012; 17 (9): 1103-1111.
- 13 Lianga L, Korogi Y, Sugahara T, et al. Normal structures in the intracranial dural sinuses: delineation with 3D contrast-enhanced magnetization prepared rapid acquisition gradient-echo imaging sequence. *Am J Neuroradiol.* 2002; 23 (10): 1739-1746.
- 14 Zhen L, Liu C, Jiang BHJ, Pang Q, et al. Preoperative evaluation of venous systems with computed tomography venography in parasagittal meningiomas. *J Comput Assist Tomogr.* 2006; 32 (2): 293-297.
- 15 Tigliev GS, Oliushin VE, Gurchin AF, et al. [The collateral venous blood flow and the surgical procedure in parasagittal meningiomas]. [Article in Russian]. *Vestn Khir Im I I Grek.* 1999; 158 (1): 9-12.
- 16 Zacharski LR, Wojtukiewicz MZ, Constantini V, et al. Pathways of coagulation/fibrinolysis activation in malignancy. *Semin Thromb Hemost.* 1992; 18 (1): 104-116.
- 17 Korte W. Changes of coagulation and fibrinolysis system in malignancy: their possible impact on future diagnostic and therapeutic procedures. *Clin Chem Lab Med.* 2000; 38 (8): 679-692.
- 18 Thron L, Arbit E. Hemostatic changes in patients with brain tumors. *J Neurooncol.* 199; 22 (2): 87-100.
- 19 Kim SE, Parker DL. Time-of-Flight Angiography. In: Carr C., Carroll TJ (eds). *Magnetic Resonance Angiography. Principles and Applications.* Springer Science + Business Media. 2012. pp 39-50.

Prof. Yuko Ono
 Department of the Diagnostic Imaging
 and Nuclear Medicine
 Tokyo Women's Medical University Hospital
 8-1 Kawada-cho
 Shinjuku-ku, 162-8666, Tokyo
 Japan
 Tel.: +81-3-3353-8111 ext. 28256
 Fax: +81-3-5269-7568
 E-mail: yono@nij.twmu.ac.jp,
 yukolein.ono@gmail.com