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Falcine Sinus: Incidence and Imaging Characteristics of Three-Dimensional Contrast-Enhanced Thin-Section Magnetic Resonance Imaging

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Objective: To evaluate the incidence, characteristics, and variations of the falcine sinus with contrast-enhanced three-dimentional (3D) thin-section magnetic resonance (MR) images.

Materials and Methods: A retrospective review identified 1531 patients (745 males and 786 females, 2 months to 85 years) who underwent cranial MR imaging including T1-weighted imaging, T2-weighted imaging, T2-weighted fluid-attenuated inversion recovery, contrast-enhanced 3D thin-section sagittal scans, and MR venography, from June 2014 to January 2016. The incidence, characteristics of the falcine sinus, and coexisted intracranial lesions were confirmed by two neuroradiologists.

Results: Falcine sinuses were identified in 81 (38 males and 43 females) cases (5.3%, 81/1531, 5 months to 76 years of age) with calibers ranging from 2.3 mm to 17.0 mm. Three major forms of falcine sinuses were defined: arch-like (n = 47), stick-like (n = 22), and bifurcated (n = 12). Persistent falcine sinuses were found in 57 cases, among which 3 cases showed complicated cerebral anomalies, and 2 cases showed smaller straight sinuses. Recanalization of falcine sinuses were found in 24 cases, including 17 cases with tumor compression, 6 cases with cerebral venous sinus thrombosis, and one case with hypertrophic meningitis.

Conclusion: Falcine sinus is not as rare as has been reported previously. Most falcine sinuses are not associated with congenital cerebral abnormalities. Diseases that cause increased pressure in the venous sinus may lead to recanalization of falcine sinus. Illustrating the characteristics of falcine sinus may prompt a more comprehensive understanding and diagnosis of associated diseases, and avoid potential surgical damage in the future.

Keywords: *Falcine sinus; Magnetic resonance imaging; Thin-section imaging; Contrast-enhanced magnetic resonance imaging*

INTRODUCTION

Falcine sinus is a normal venous channel in falx cerebri which connects the vein of Galen and the posterior part of superior sagittal sinus (SSS) during the prenatal period (1-6), and normally closes before or shortly after birth. A falcine sinus that fails to close is defined as persistent falcine sinus, which has been reported in most previous studies as a rare intracranial venous anomaly frequently associated with complicated cerebral abnormalities (6-14).

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Systematic investigation with a large sample series was rare (15). The purpose of this study was to evaluate the incidence, anatomic characteristics, and variations of falcine sinus, to assess its clinical significance and obtain a more comprehensive understanding of falcine sinus using a series of cranial MRIs with contrast-enhanced three-dimentional (3D) thin-section sagittal scans.

MATERIALS AND METHODS

Patient Population

This study was approved by our Institutional Review Board. Contrast-enhanced 3D thin-section sagittal cranial magnetic resonance (MR) images of patients in our hospital from June 2014 to January 2016 were evaluated retrospectively. Patients with a history of neurosurgery or open brain trauma were excluded. A total of 1531 consecutive cases were reviewed, including 745 males and 786 females, aged from 2 months to 85 years.

Scan Protocol

All images were obtained with a 3T MR system (MAGNETOM TrioTim, Siemens Healthcare, Erlangen, Germany). MR imaging sequences were axial T1-weighted imaging, T2-weighted imaging, coronal T2-weighted fluid attenuated inversion recovery sequence, 3D thin-section contrast-enhanced sagittal scanning (3D T1-weighted magnetization-prepared rapid gradient echo sequences, repetition time [TR] = 1750 ms, echo time [TE] = 3.26 ms, field of view [FOV] = 226 x 226 mm, matrix = 384 x 384, slice thickness = 0.6 mm, slice gap = 0) and MR venography (gradient-recalled echo sequence, TR = 2.6–2.9 ms, TE = 1.0–1.1 ms, FOV = 640 x 640 mm) after administration of 0.2 mmol/kg gadoterate meglumine (Beilu Pharmaceutical Co., Ltd, Beijing, China).

Image Analysis

All the images were observed by two senior neuroradiologists separately, and findings were confirmed based on the consistency between the opinions of the two neuroradiologists. Agreements were achieved after comprehensive discussions about the few cases in which different opinions were held initially by the two radiologists. The presence of the falcine sinus was divided into two categories according to Ryu's study (15): 1) persistent falcine sinus without venous sinus disease or compression; 2) recanalized falcine sinus with the existence of lesions causing venous sinus obstructions. Analysis of the images included: 1) review for the presence of falcine sinus; 2) definition of the shape and caliber of the falcine sinus; 3) definition of the coexisted diseases that increase the pressure of venous sinuses; 4) situations with congenital cerebral abnormalities; 5) comparison of the falcine sinuses before and after surgeries or other medical treatments; and 6) definition of other cranial lesions and anomalies. Statistical analysis was performed for patients' demographic information. Kolmogorov-Smirnov test was applied for the test of normality.

RESULTS

Demographic Findings of Falcine Sinus

For the 1531 consecutive cases, the primary clinical causes for MR imaging were headache (459, 30.0%), confirmed cerebral tumor (245, 16.0%), cranial nerve disorders (196, 12.8%), dizziness (182, 11.9%), systemic diseases (such as lupus erythematosus, screening for metastasis, etc.; 93, 6.1%), asthenia (84, 5.5%),

Table 1. Incidence of Falcine Sinus according to Age Groups

Range of Age (Years)	Number of Subjects	Number of Falcine Sinuses	Percentage of Subjects with Falcine Sinus
0–10	108	7	6.5
11–20	133	8	6.0
21–30	127	9	7.1
31–40	265	18	7.0
41–50	340	15	4.4
51–60	323	14	4.3
61–70	173	8	4.6
71–80	53	2	3.8
81–90	9	0	0
Total	1531	81	5.3

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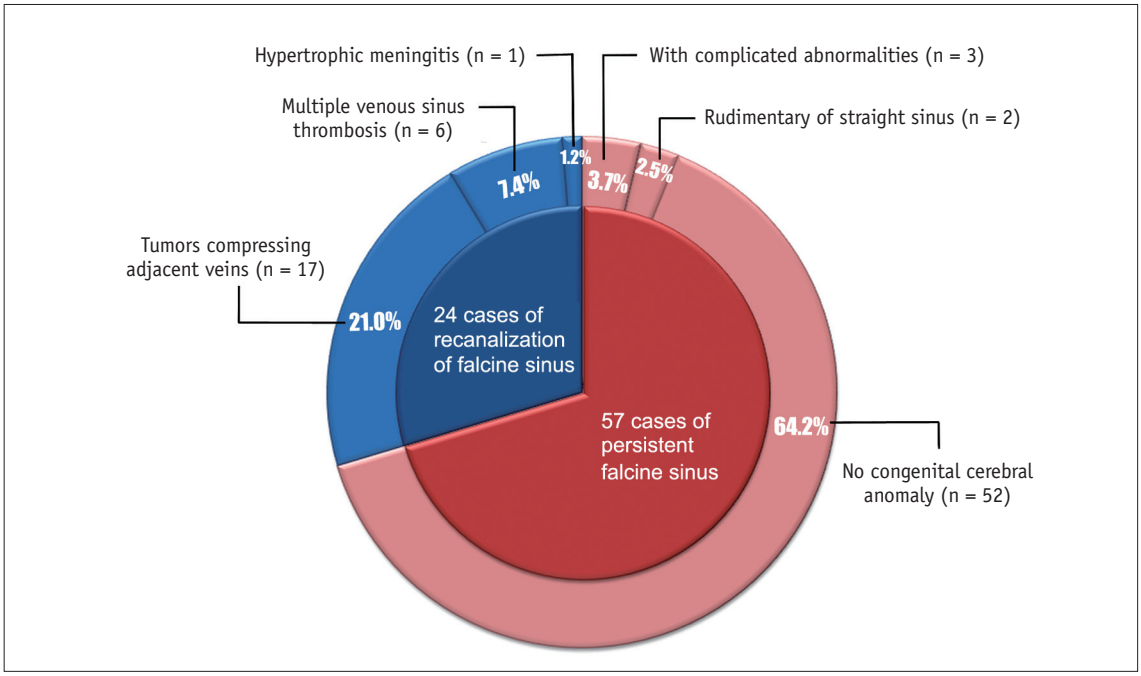

Fig. 1. Associated imaging findings in subjects with falcine sinuses of different clinical types.

intracranial hypertension (74, 4.8%), vomiting (66, 4.3%), epilepsy (34, 2.2%), tinnitus (32, 2.1%), dystaxia (25, 1.6%), and others (insomnia, disorder of consciousness, etc.; 41, 2.7%).

Eighty-one out of 1531 patients were identified with falcine sinuses (5.3%), including 38 males and 43 females, with ages ranging from 5 months to 76 years, which were normally distributed (Table 1). The incidence of falcine sinus in the two sexes was similar, with 5.1% (38/745) in males, and 5.5% (43/786) in females. Our results indicated that the incidence of falcine sinus was evenly distributed indifferent sexes and ages.

Clinical Findings of Falcine Sinus

A total of 81 patients showed falcine sinuses. Fifty-seven cases (3.7%, 57/1531) exhibited persistent falcine sinuses (Fig. 1). 1) Three cases had complicated abnormalities, including one case with the absence of the splenium of corpus callosum, multiple cysts, and parietal abnormalities of schizencephaly associated with gray matter heterotopia next to the central line; one case with ectasia of superior SSS, falcine sinus and the vein of Galen, associated with Chiari's I malformation; and one case with partial absence of the corpus callosum and arteriovenous malformation of the pericallosal vessels (Fig. 2). A rudimentary straight sinus was observed in the above 3 cases. 2) Two cases only showed rudimentary of the straight sinus without other

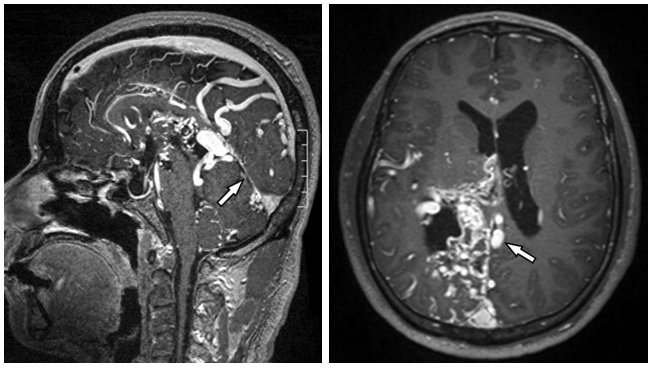

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Fig. 2. 43-year-old male with multiple cerebral abnormalities.
A. Sagittal contrast-enhanced MR image demonstrated absence of splenium of corpus callosum and vascular malformations in corpus callosum and lateral ventricles. Straight vessel was narrow (arrow), with two vessels originating from anterior part and connecting to SSS. **B.** Axial contrast-enhanced MR image showed that above vessels were in posterior part of falx cerebri (arrow). Vascular malformations were mainly located near right lateral ventricle. MR = magnetic resonance, SSS = superior sagittal sinus

malformations. 3) The other 52 cases did not show any congenital cerebral anomalies.

Twenty-four cases (1.6%, 24/1531) exhibited recanalization of falcine sinus (Fig. 1). 1) Seventeen cases showed tumors compressing the adjacent veins (Fig. 3), including 11 cases of meningioma, 2 cases of hemangiopericytoma, and 1 case each of the following: ganglioglioma, pilocytic astrocytoma, medulloblastoma, and giant tumor in the posterior cranial fossa. In 10 subjects,

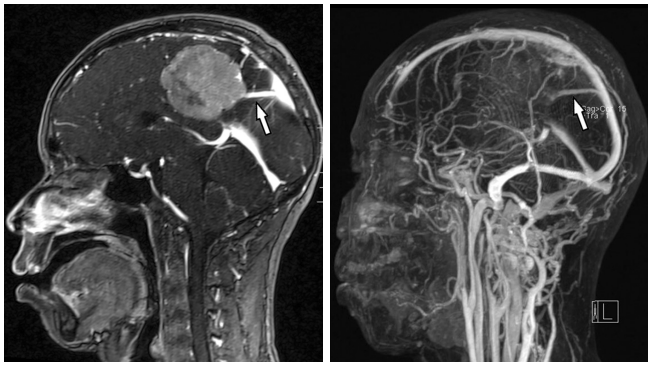

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Fig. 3. 34-year-old male with meningioma next to falx cerebri.
A. Sagittal contrast-enhanced MR image demonstrated close relationship of tumor near middle falx cerebri to falcine sinus (arrow). Straight sinus was normal. **B.** MR venography image showed arch-like vessel connecting anterior part of straight sinus and posterior part of SSS (arrow).

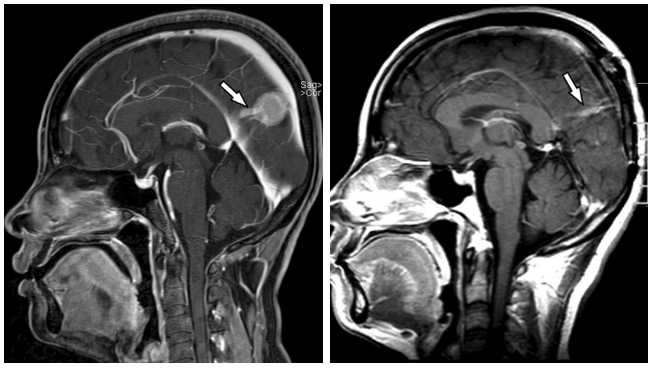

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Fig. 4. 35-year-old female with meningioma next to falx cerebri.
A. Sagittal contrast-enhanced MR image showed that small tumor near posterior part of falx cerebri had close relationship with falcine sinus (arrow). Corpus callosum and straight sinus appeared normal. **B.** Sagittal contrast-enhanced MR image showed parietal bone defect after removal of tumor; stick-like falcine sinus was preserved (arrow).

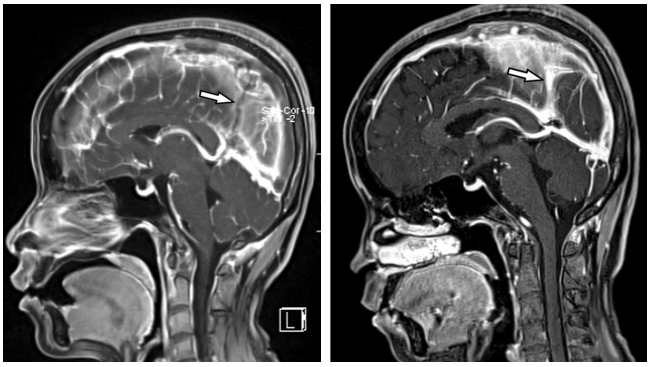

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Fig. 5. 32-year-old female with multiple venous sinus thrombi.
A. Sagittal contrast-enhanced MR images demonstrated defuse thrombosis in SSS, straight sinus and torcular, herophili. Falcine sinus was filled with thrombus (arrow) with distinguishable edge. **B.** Sagittal contrast-enhanced MR image showed partial absorption of thrombi in SSS and torcular herophili after operation. Thrombi in falcine sinus and straight sinus disappeared and falcine sinus was identified (arrow).

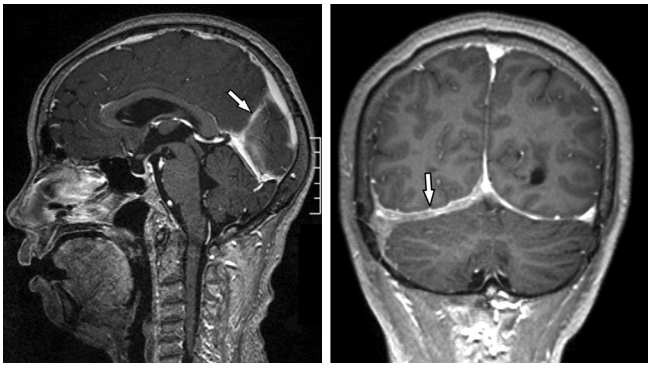

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Fig. 6. 26-year-old female with hypertrophic meningitis.
A. Sagittal contrast-enhanced MR image demonstrated stick-like falcine sinus (arrow). **B.** Coronal contrast-enhanced MR image detected hypertrophic right tentorium of cerebellum (arrow). Right transversal sinus and sigmoid sinus were compressed.

of the tumors located next to the falx cerebri, 4 were in the posterior fossa/cerebellum, and 3 were in the middle fossa. Except for 2 subjects lost to follow-up, the other 15 cases underwent surgical operations; follow-up MR examinations showed no changes of the recanalized falcine sinuses (Fig. 4). 2) Six cases presented with multiple venous sinus thrombosis mainly involving SSS and transverse sinus. One case showed falcine sinus thrombosis (Fig. 5). MRI follow-up examinations of the 6 cases after treatment demonstrated no change of the falcine sinuses. 3) One case showed hypertrophic meningitis (Fig. 6).

Imaging Characteristics and Classification of Falcine Sinus

Contrast-enhanced 3D thin-section sagittal MR scans clearly showed direction, anatomical structures and connection with the surrounding structures of the falcine sinus. In our study, the falcine sinus presented as blood vessels connecting the vein of Galen, or as the anterior part of the straight sinus with SSS, with calibers between 2.3 mm to 17 mm (7.3 ± 4.1 mm). They were categorized into 3 groups based on their imaging characteristics: 1) 47 cases of arch-like falcine sinus that exhibited as an curved vessel protruding towards the front (Fig. 3), three of these cases were located near the occipital pole connecting the anterior part of the straight sinus and the posterior part of SSS; 2) 22 cases of stick-like falcine sinuses that exhibited as a straight vessel and in most cases with a large caliber (Fig. 4); 3) 12 cases of bifurcated or branch-like falcine sinuses

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that connected the vein of Galen or the anterior part of the straight sinus and the posterior part of SSS with two or more branches of vessels (Fig. 2). One case of branch-like falcine sinus was initially mistaken as the drainage vessel of an arteriovenous malformation (Fig. 2).

DISCUSSION

Embryology of Falcine Sinus

Falcine sinus is a vascular channel between the two layers of falx cerebri that is present during the fetal period and usually closes before birth (1-3). Continued presence or recanalization of the falcine sinus after birth is considered to be a variation or anomaly. During early embryonic development, the primitive falx cerebri contains the sagittal plexus, a mesh of anastomotic venous loops. As the dorsal dominant venous channel of the sagittal plexus eventually develops into the anterior aspect of SSS, the ventral aspect of the sagittal plexus becomes the inferior sagittal sinus and the straight sinus, and the smaller channels between them disappear (1, 2, 4). With the development of the occipital lobe, the SSS and straight sinus start extending towards the occipital pole, recruiting more caudal venous loops of the sagittal plexus and forming a complete SSS and straight sinus. Falcine sinus is formed by one of the caudal anastomotic loops of the sagittal plexus (1, 2), and disappears after complete development of the SSS and straight sinus. The development of the falcine sinus is closely associated with that of the posterior aspect of the SSS and the straight sinus (5, 6).

Some studies suggested that persistent or recanalized falcine sinus might result from an enlargement of certain venous channels caused by an obstruction of the venous sinuses (1, 2). Although located between posterior part of the SSS and the vein of Galen or the anterior part of straight sinus, the falcine sinuses observed in our study varied in morphology, including arch-like, stick-like, bifurcation and branches. This indicated that instead of developing from one specific venous channel of the sagittal plexus, the falcine sinus may form by a random opening of certain venous channels or the combination of a number of small channels. These findings might inspire further thought when studying the embryology of falcine sinus. Moreover, our study found that the falcine sinuses near the occipital pole appeared to be small and the upper end seemed to be close to torcular herophili, indicating that these falcine sinuses might be the traces of incomplete degradation of sagittal venous plexus during the convergence of the SSS and straight sinus towards the occipital pole.

The Incidence of Falcine Sinus

Previous studies (6-13) reported that falcine sinus was a rare congenital variation. Ryu (15) challenged this conclusion when they analyzed the CT cerebral venous angiography of 586 cases and found that the incidence was 2.1%. Our study of 1531 cases showed that the incidence of falcine sinus and persistent falcine sinus was 5.3% and 3.7%, respectively, which was in consistent with the conclusion that falcine sinus might not be a rare variation. The incidence of falcine sinus in our study was higher than that in Ryu's study, which might resulted from the difference of imaging method. We analyzed the thin section enhanced MRI images, while Ryu's study was based on CT venous angiography. MRI image has better soft tissue resolution than CT, and the minimum caliber of the falcine sinus observed in our study was 2.3 mm.

Kaplan et al. (16) conducted a cadaveric study and found 16 (21%) out of 78 specimens had venous channels connecting the superior and inferior sagittal sinus, which also indicated the possibility of high incidence of falcine sinus. In addition, Kaplan's study suggested that such venous channels were seen in all ages, which is in accordance with the even distribution of falcine sinus in subjects with different ages in our study.

Clinical Significance of Falcine Sinus

Diagnosis as a Congenital Variation

Anomalies of straight sinus and SSS are commonly combined with falcine sinus as a result of their embryonic correlations during the fetal period (4, 6, 7, 15). These anomalies generally include aplasia, or absence of the venous sinus, and their incidence is low. Most cases are asymptomatic. Only 2 cases were found in our study.

Most cases of falcine sinus combined with cerebral abnormalities were presented in case reports. The reported abnormalities were as followed: dysplastic tentorium cerebelli and malposition of the SSS (15), dysplastic tentorium and enlarged parietal foramina (6, 8), dilation of the vein of Galen, and mid-brain arteriovenous malformation (9, 10), pericallosal arteriovenous malformation associated with absence of the posterior parts of the corpus callosum (9), total absence of the corpus callosum (9), Apert's syndrome (acrocephalosyndactyly) (9),

osteogenesis imperfecta, and Chiari's II malformation (9), parietal skull defect, and meningoencephalocele (11). Only 3 out of 57 cases in our study presented with complicated malformations; persistent falcine sinus with complicated malformation suggest that almost all malformations appeared close to the midline region. We speculate that persistent falcine sinus may be part of the midline dysplasia.

It has long been thought that persistent falcine sinus was usually associated with complicated abnormalities, probably because these patients (mostly children) sought medical treatment due to symptoms related to cranio cerebral anomalies. Asymptomatic patients were less likely to undertake systematic craniocerebral examinations; therefore large scale screenings were rare. Our study and Ryu's (15) large-scale investigation both indicated that persistent falcine sinus is not frequently associated with complicated craniocerebral abnormalities. It should be noted however, that both study subjects were Asians, and thus may not represent all ethnic groups.

Based on our observations, several diagnostic considerations should be noted: 1) falcine sinus should not be considered as venous malformation when there is no associated abnormality; 2) as a special venous sinus, falcine sinus might also have venous thrombosis. When venous thrombosis forms in falcine sinus, contrast-enhanced MRI scan can fail to identify its position without the filling of contrast medium, which leads to missed diagnosis; 3) when adjacent vascular malformations exist, falcine sinuss should not be mistaken as massive drainage vessels, and should be determined by its relationship to SSS and straight sinus.

Function as a Venous Drainage Channel

As a special venous channel, falcine sinus can be recanalized in two main circumstances: straight sinus embolism during the fetal period, and chronic obstruction of the straight sinus due to the pressure of adjacent tumors in adults (1). Recanalization of the falcine sinus caused by venous sinus thrombosis has also been described in previous studies (1, 15).

There were 24 cases of recanalized falcine sinus in the current study. We speculate that increased pressure inside venous sinuses might lead to recanalization of potential venous channels such as falcine sinus. In our study, the external causes of increased inner pressure were tumor compressions (especially those near the meninges and closely associated with the venous sinus) and compressions on venous sinuses by the thickened meninges due to hypertrophic meningitis. The internal cause was venous sinus thrombosis, likely due tothe recanalized falcine sinus increasing venous drainage and building collateral circulation (13). Follow-up contrast-enhanced MR images of 21 cases (15 cases of tumor after surgery and 6 cases of venous sinus thrombosis after thrombolytic therapy) demonstrated that all the recanalized falcine sinuses remained open with no significant changes in shapes or locations after treatment. We believe that the recanalized falcine sinuses may no longer close probably due to the unidirectional regulation of blood circulation of falcine sinus.

Consideration during Surgery

During endovascular or surgical obliteration of the straight sinus, the falcine sinus may assist venous drainage and is vital to cerebral blood drainage and intracranial pressure regulation (17). For surgeries involving falx cerebri, the existence of the falcine sinus may increase the risk of iatrogenic hemorrhage. Attention should be paid to the falcine sinus in the preoperative examination, especially with tumors such as meningioma that tend to compress venous sinuses (13).

This study had limitations. The subjects of this study were all Asians and may not represent all ethnic groups. In addition, cerebral digital subtraction angiography was not used to confirm the MR venography results in this study.

In conclusion, our investigation of a large number of retrospective cases using cranial magnetic resonance imaging with contrast-enhanced 3D thin-section sagittal scans suggested that falcine sinus is not a rare variation as reported before, and is not frequently associated with complex craniocerebral abnormalities. Clearly illustrating the characteristics of falcine sinus with the use of MR imaging may prompt more comprehensive understanding and diagnosis of the associated diseases and avoid potential surgical damage.

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