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Original Article

Access-route Visualization Using Ultrasonography and CT Angiography to Predict the Feasibility of Transvenous Embolization via the Facial Vein for Cavernous Sinus Dural Arteriovenous Fistulas

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Objective: Transvenous embolization (TVE) is an effective treatment for cavernous sinus dural arteriovenous fistulas (CS-DAVFs). The facial vein (FV) can be used as an access route for TVE when a trans-inferior petrosal sinus (IPS) approach is difficult. We evaluated the usefulness of combining ultrasonography (US) with computed tomography angiography (CTA) for confirming that the FV is a suitable access route for treating CS-DAVFs.

Methods: Trans-FV TVE was planned for five CS-DAVF patients in whom the shunt point was located in the posterior compartment of the CS and anterior venous drainage predominantly occurred via the superior ophthalmic vein (SOV). The anterior drainage route was examined with CTA and US. We reviewed the relationships between preoperative CTA/US findings and the accessibility of CS-DAVFs via the FV.

Results: The periorbital and perimandibular drainage pathways were clearly more visible on US than on CTA, and the cervical and thoracic drainage pathways were more visible on CTA than on digital subtraction angiography (DSA). CS-DAVFs were accessible via the FV when (1) the entire drainage pathway could be confirmed on CTA and US, (2) the periorbital and perimandibular pathways were unclear on CTA, but could be confirmed on US, or (3) the FV pathway drained into the internal jugular vein (IJV) or external jugular vein (EJV). On the other hand, TVE was challenging to perform via the FV when (1) the periorbital pathway was unclear on CTA and US, (2) the FV pathway drained into the brachiocephalic vein, or (3) the SOV thrombosed intraoperatively. In all five patients, TVE for CS-DAVFs performed via the FV or IPS was successful.

Conclusion: CTA and US are useful for confirming the anterior access route for trans-FV TVE for CS-DAVFs and predicting the feasibility of such treatment. Our findings suggest that CS-DAVFs can be accessed via the FV if the periorbital drainage pathway can be confirmed on US, even if the pathway is unclear on CTA.

Keywords ▶ cavernous sinus dural arteriovenous fistula, facial vein, computed tomography angiography, ultrasonography, access route

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Introduction

Transvenous embolization (TVE) is the first-choice option for the radical treatment of cavernous sinus dural arteriovenous fistulas (CS-DAVFs).[1–3] Generally, in TVE for a CS-DAVF, the inferior petrosal sinus (IPS) approach is selected as the route to the CS because of the accessibility it provides. However, the facial vein (FV) can be used as an alternative route if performing TVE via the IPS would be difficult. Compared with the route via the IPS, the access route via the FV is tortuous and long, and the outflowing blood vessels of the FV exhibit numerous variations. Therefore, performing trans-FV TVE for CS-DAVFs might be challenging.[4,5] In this study, we analyzed the usefulness of a combination of ultrasonography (US) and computed tomography angiography (CTA) for assessing the FV access route and predicting the feasibility of trans-FV TVE for CS-DAVFs.

Patients and Methods

Study population

Of the 8 patients who underwent endovascular treatment for CS-DAVFs at our hospital during the period from May 2017 to October 2019, we retrospectively analyzed the cases of five patients with CS-DAVFs who were scheduled to be treated with trans-FV TVE. The patients were 2 males and 3 females aged 70–77 years (median: 73 years). The patients' preoperative CTA and US findings and the TVE access routes employed were reviewed.

Preoperative imaging findings

In all 5 patients, digital subtraction angiography (DSA) of the bilateral internal carotid arteries, external carotid arteries, and vertebral arteries was performed to diagnose the CS-DAVFs. The anterior drainage routes from the superior ophthalmic vein (SOV) to the cervical portion were also evaluated using head and neck CTA and US before the operation. Using the patients' records, we determined the locations of shunt points, feeders, drainers, and the terminus of the FV; whether the entire length of the venous drainage route could be visualized on CTA and/or US; and the access routes to the CS-DAVFs.

Computed tomography angiography

All CT scans were obtained on a 320-detector row CT scanner (Aquilion ONE; Canon Medical Systems, Tochigi, Japan). We delivered 300 mgI/kg of non-ionic contrast material (iomeprol: 300 mgI/mL Iomeron; Eisai, Tokyo, Japan) for a fixed period of 15 s to all patients using a dual-shot injector (DUAL SHOT GX7; Nemoto Kyorindo, Tokyo, Japan). Images were reconstructed with a 0.5-mm slice thickness. The scan parameters were as follows: slices: 32×0.5 mm; tube voltage: 120 kVp; rotation time: 0.4 s; auto-exposure control index: 6; matrix: 512×512. The images were reconstructed with AIDR 3D (mild setting) using a standard kernel (FC43).

Ultrasonography

Color Doppler flow imaging (CDFI) was performed using LOGIQ E9 (GE Healthcare Japan, Tokyo, Japan) with an 8–15 MHz broadband linear array transducer. In the CDFI examinations, transverse color flow images and a pulsed Doppler recording were produced from the SOV, angular vein, and FV to the terminus of the FV. These CDFI studies provided information on the size, flow direction, pulsed Doppler wave curve, and flow velocity of the drainage route.

Therapeutic strategies and endovascular procedures

We planned to perform TVE via the FV for CS-DAVFs in patients in which the shunt point was located in the posterior compartment of the CS and anterior venous drainage mainly occurred via the SOV because this provided access to the shunt point through the anterior drainage route. In all cases, catheterization to the CS via the FV was attempted first. If it was difficult to insert a catheter into the CS via the FV, the access route was changed to the trans-IPS approach. Catheters were inserted into the feeding arteries via the femoral artery and were used for angiographic control and roadmapping. For the trans-FV TVE, an 8Fr guiding catheter or a 6Fr guiding sheath was navigated to the opening of the common FV under the support of intraoperative radioscopy and roadmaps. After introducing a microguidewire into the FV, a microcatheter was passed through the FV to the CS using the triple coaxial method consisting of an 8Fr guiding catheter or a 6Fr guiding sheath, a 3.4 Fr distal access catheter, and a microcatheter while following the roadmap. The procedure was performed while referring to a 3D image created using CTA, which included bone structures, and the terminus and pathway of the FV were confirmed. Using biplane angiographic equipment, coils were introduced into the CS to occlude the lesion until no shunt flow was seen. All patients were heparinized during the procedure.

Results

Characteristics of the CS-DAVFs

The findings of the 5 patients are summarized in **Table 1**. The CS-DAVF was located on the right in 2 patients and on the left in the other three patients. In all 5 patients, the shunt points were positioned in the posterior portion of the CS, and anterior venous outflow toward the SOV was observed. Four of the patients (patients 1–3 and 5) had bilateral

Table 1 The characteristics of CS-DVAF, observation of FV drainage route, and access route to CS-DAVF of five patients

Patient no.	Age (yr) / sex	Characteristics of CS-DAVF				Observaton of FV drainage route		Access route to CS-DAVF
		Shunt point	Feeders	Drainers	FV termination	CTA	US	
1	68/F	Lt PM	Lt AMA, MMA, AFR Rt AFR	Lt SOV, SPS	IJV	Observed	Observed	Lt FV
2	72/M	Rt PL	Rt AMA, MMA, AFR, MHT	Rt SOV, SPS	EJV	Partially observed (*1)	Observed	Rt FV
3	75/M	Rt PL	Rt AMA, AFR	Rt SOV	IJV	Partially observed (*1)	Partially observed (*2)	Rt IPS
4	73/F	Lt PL	Lt AMA, MMA, AFR, APA, MHT	Bil SOV Lt IPS (*3)	ITV-BV	Observed	Observed	Lt IPS
5	77/F	Lt PM	Rt MMA, AFR, APA, MHT Lt MMA, APA	Lt SOV (*4)	IJV	Observed	Observed	Lt IPS

*1: The drainage flow was unclear between SOV and angular vein and mandibular portion.
*2: The drainage flow was unclear between SOV and angular vein.
*3: The left IPS was highly narrowed.
*4: The SOV was thrombosed on intraoperative angiography.
AFR: artey of foramen rotundum; AMA: accessory menigeal artery; APA: ascending pharyngeal artery; BV: brachiocephalic vein; CS-DAVF: cavernous sinus dural arteriovenous fistula; CTA: computed tomography angiography; EJV: external jugular vein; FV: facial vein; IJV: internal jugular vein; IPS: inferior petrosal sinus; ITV: inferior thyroid vein; MHT: meningohypophyseal trunk; MMA: middle menigeal artery; PL: posterolateral; PM: posteromedial; SOV: superior opthalmic vein; SPS: superior petrosal sinus; US: ultrasonography

occluded IPSs, and one had a highly narrowed ipsilateral IPS and an occluded contralateral IPS (patient 4).

Preoperative CTA and US imaging findings

On preoperative CTA and US, the entire length of the venous drainage route could be confirmed in 3 patients (patients 1, 4, and 5). On CTA, the outflow routes from the SOV to the angular vein and the mandibular section of the drainage route were unclear in patients 2 and 3. On US, blood flow signals for the FV were confirmed in the mandibular section of the drainage route in patients 2 and 3, but it was difficult to detect blood flow signals in the section from the SOV to the angular vein in patient 3. In the periorbital and mandibular sections, US was more useful for route confirmation than CTA. The terminus of the FV was located in the internal jugular vein (IJV) (patients 1, 3, and 5), the external jugular vein (EJV) (patient 2), or the brachiocephalic vein via the inferior thyroid vein (ITV; patient 4). In patient 5, good outflow from the SOV to the IJV was seen on the preoperative examination performed 8 days before the operation, but the drainage route was unclear on intraoperative DSA due to thrombosis of the section between the SOV and the FV. The cervical and thoracic drainage routes were more clearly identifiable on CTA than on DSA.

The relationships between the access routes to the CS-DAVFs and the preoperative CTA and US imaging findings

In the cases in which the entire length of the drainage route from the SOV to the IJV or EJV could be observed on preoperative CTA and/or US (i.e., patients 1 and 2), the FV could be used as an access route to the CS-DAVFs. In patient 2, the drainage route from the SOV to the angular vein and the mandibular section of the drainage route were unclear on CTA, but they were clearly observable on US. The FV could not be used as an access route to the CS-DAVFs in the other three patients for the following reasons. In patient 3, catheterization between the angular vein and SOV was difficult as the drainage route was unclear on CTA and US. In patient 4, CTA and US confirmed the route of the outflow tract, but catheterization of the FV, which drained to the brachiocephalic vein, was difficult because of the instability of the guiding catheter. In patient 5, the FV was not opaque on intraoperative DSA as the FV had thrombosed, and it was difficult to pass through the FV in the mandibular region. In these 3 patients, a microcatheter was inserted into the CS via the ipsilateral thrombosed IPS. In all 5 patients, the placement of coils in the CS resulted in complete closure of the fistula.

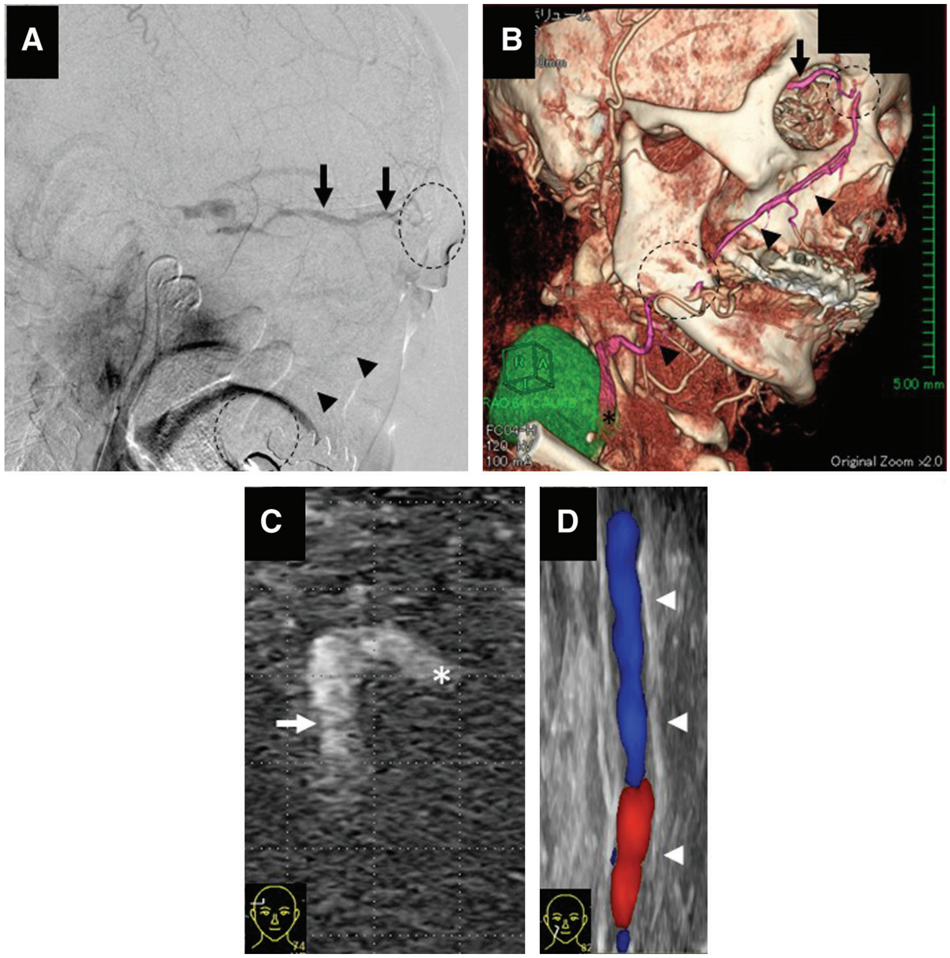

Fig. 1 (**A**) Preoperative lateral view of the right external carotid angiogram showing a right-sided CS-DAVF with venous drainage from the SOV (arrows) into the FV (arrowheads) and the SPS. The bilateral IPSs were occluded. The drainage route between the SOV and the angular vein, and the mandibular section were unclear on DSA (dotted circles). (**B**) CTA showing the drainage route from the right SOV (arrow) to the right EJV (asterisk) through the FV (arrowheads). The drainage route between the SOV and the angular vein, and mandibular section were unclear on CTA (dotted circles). (**C** and **D**) The blood flow signals of the right SOV (arrow), the angular vein (asterisk), and the FV (arrowheads) were clearly observed on US but unclear on CTA. CS-DAVF: cavernous sinus dural arteriovenous fistula; CTA: computed tomography angiography; DSA: digital subtraction angiography; EJV: external jugular vein; FV: facial vein; IPSs: inferior petrosal sinuses; SOV: superior ophthalmic vein; SPS: superior petrosal sinus; US: ultrasonography

Illustrative cases

Patient 2

A 72-year-old Japanese male suffered from right-sided chemosis and exophthalmos. DSA revealed a right-sided CS-DAVF, which was fed by the right accessory meningeal artery (AMA), middle meningeal artery (MMA), the artery of the foramen rotundum (AFR), and the meningohypophyseal trunk (MHT) and exhibited venous drainage from the SOV into the FV and the right superior petrosal sinus (SPS). The bilateral IPSs were occluded (**Fig. 1A**). The drainage route between the SOV and the angular vein, and the mandibular section of the drainage route were unclear on DSA (**Fig. 1A**) and CTA (**Fig. 1B**), but blood flow signals were clearly observed on US over the entire length of the drainage route, including in the segments that were unclear on DSA and CTA (**Fig. 1C** and **1D**). A guiding catheter was placed in the FV, and a microcatheter was navigated to the CS via the FV. The CS was completely occluded by embolizing it using coils.

Patient 3

A 75-year-old Japanese male suffered from right-sided chemosis, diplopia, and exophthalmos. DSA revealed a right-sided CS-DAVF, which was fed from the right AMA and AFR and exhibited venous drainage from the right SOV and the FV into the IJV. The bilateral IPSs were

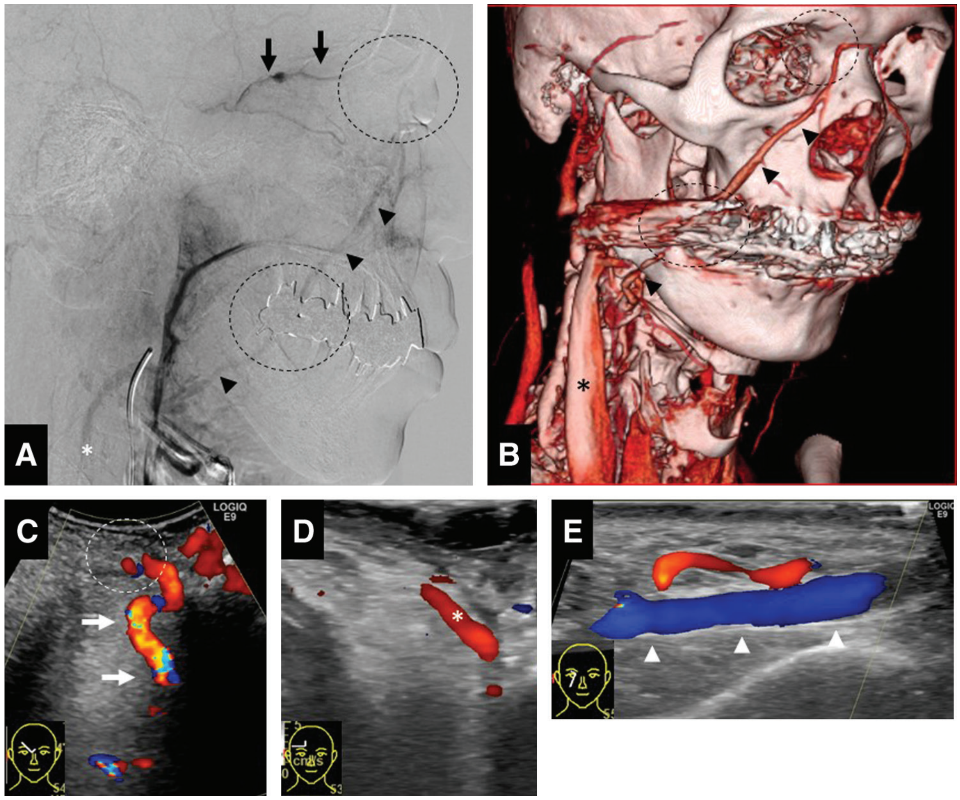

Fig. 2 (**A**) Preoperative lateral view of the right external carotid angiogram showing a right-sided CS-DAVF with venous drainage from the right SOV (arrows) and the FV (arrowheads) into the IJV. The bilateral IPS were occluded. The drainage pathway between the SOV and the angular vein, and mandibular section were unclear on DSA (dotted circles). (**B**) CTA showing the drainage pathway to the right IJV (asterisk) via FV (arrowheads). The drainage pathway between the SOV and the angular vein, and mandibular section were unclear on CTA (dotted circles). (**C–E**) Blood flow signals of the right SOV (arrows), the angular vein (asterisk), and the FV (arrowheads) were evident, but the continuity of the blood flow signals from the SOV to the angular vein was not confirmed on US (dotted circle). CS-DAVF: cavernous sinus dural arteriovenous fistula; CTA: computed tomography angiography; DSA: digital subtraction angiography; FV: facial vein; IJV: internal jugular vein; IPS: inferior petrosal sinus; SOV: superior ophthalmic vein; US: ultrasonography

occluded. The drainage pathway between the SOV and the angular vein was unclear on DSA and CTA (**Fig. 2A** and **2B**). On US, blood flow signals were evident in the SOV, angular vein, and the FV (**Fig. 2C–2E**), but the continuity of the blood flow signals from the SOV to the angular vein was not confirmed (**Fig. 2C**). We tried to perform trans-FV TVE, but it was difficult to pass a microcatheter through to the SOV beyond the angular vein, which was unclear on CTA and US, using the triple coaxial method. We decided to switch the access route to the trans-IPS approach. A guiding catheter was introduced into the right IPS, and a microcatheter was inserted into the CS via the thrombosed IPS. The CS was completely occluded by embolizing it using coils.

Patient 4

A 73-year-old Japanese female suffered from left-sided chemosis, diplopia, and exophthalmos. DSA revealed a left-sided CS-DAVF, which was fed by the left AMA, MMA, AFR, ascending pharyngeal artery, and MHT and exhibited dominant anterior venous drainage into the bilateral FV via the SOV. An occluded right IPS and a highly narrowed left IPS were observed (**Fig. 3A**). The outflow route of the FV in the cervical region was unclear on DSA (**Fig. 3B**), but head and neck CTA (**Fig. 3C** and **3D**) and US (**Fig. 3E**) revealed that the FV flowed out into the left brachiocephalic vein via the left ITV. It was possible to guide the microcatheter halfway through the ITV based on intraoperative radioscopy, roadmapping, and the preoperative CTA findings, but trans-FV TVE was difficult due to the instability of the guiding catheter (**Fig. 3F**). We decided to switch the access route to the trans-IPS approach. A guiding catheter was introduced into the left IPS, and microcatheters were inserted into the CS. The CS was completely occluded by embolizing it using coils.

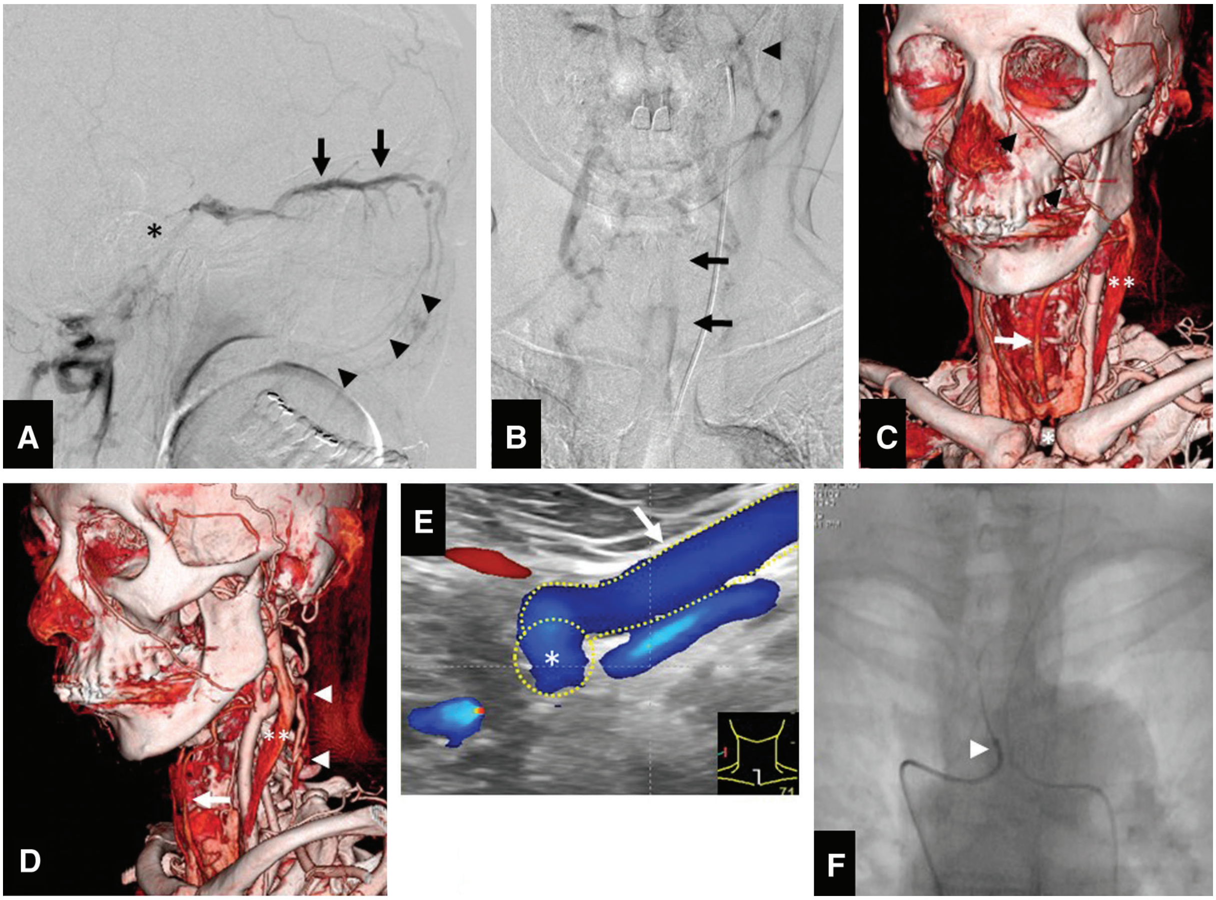

Fig. 3 (**A**) Preoperative lateral view of the left external carotid angiogram showing left-sided CS-DAVF with venous drainage into the bilateral FV (arrowheads) via the SOV (arrows), and the highly narrowed left IPS (asterisk). (**B**) The outflow route of the FV (arrowhead) in the cervical region was unclear on DSA (arrows: ITV). (**C and D**) CTA showing the left FV (arrowheads) flowed out into the left brachiocephalic vein (asterisk) via the left ITV (arrows) (double asterisks: IJV; arrowheads: EJV). (**E**) US showing the left FV flowed out into the left brachiocephalic vein (asterisk) via the left ITV (arrow). (**F**) Catheterization to the FV was difficult due to the instability of the guiding catheter in the left brachiocephalic vein (arrowhead: tip of the guiding catheter). CS-DAVF: cavernous sinus dural arteriovenous fistula; CTA: computed tomography angiography; DSA: digital subtraction angiography; EJV: external jugular vein; FV: facial vein; IJV: internal jugular vein; ITV: inferior thyroid vein; US: ultrasonography

Discussion

Our retrospective analyses revealed that the FV can be used as an access route to reach CS-DAVFs in cases in which the FV drains out to the IJV or EJV and can be visualized over its entire length using a combination of US and CTA.

The diagnosis of CS-DAVFs is made based on the clinical symptoms that are determined by the venous drainage patterns. These symptoms include exophthalmos, chemosis, ocular edema, diplopia, proptosis due to orbital hypertension, and pulsatile tinnitus.[6] Patients who display reflux into the intracranial veins are at increased risk of intracranial hemorrhaging and venous infarction. Treatment is recommended for patients with persistent clinical symptoms, such as diplopia, visual loss, headaches, and severe cosmetic disfigurement, or that exhibit reflux into the intracranial veins, to reduce or occlude the abnormal shunt flow.[2,6]

TVE is the first-choice treatment for CS-DAVFs,[2,4,6] and the trans-IPS approach is commonly selected as an access route for reaching pathological shunts involving the CS because of the shortness, straightness, and safety of this route and the fact that it allows the stable positioning of a guiding catheter in the IJV.[1,3,7,8] Although performing TVE via an occluded IPS is often possible due to advances in materials and treatment techniques,[7,8] a thrombosed IPS can prevent a successful trans-IPS approach to a CS-DAVF.[1,9] Various alternative access routes to the CS other than via the IPS have been reported, including routes involving the FV,[3–5, 7,9,10,11] SPS,[12] frontal vein,[3] retromandibular vein,[13] superficial temporal vein,[3,14] pterygoid plexus,[15] or cortical vein.[16] When performing TVE via an occluded IPS is not feasible, the SOV is often selected as an alternative access route to the CS.[4,5,7,10]

The SOV has been recommended as an access route for reaching the anterior compartment of the CS, especially in cases involving occluded IPSs.[17] However, the absence of acute thrombosis of the SOV should be confirmed after catheter navigation through the FV, angular vein, and SOV.[4] When venous outflow via the SOV is obstructed without obstruction of the target fistula, increased cortical venous drainage might result in cerebral hemorrhaging and/or neurological complications.[4,15]

Several research groups have reported that performing a trans-FV TVE for a CS-DAVF is difficult because of the tortuousness and length of the pathway, and there are numerous variations in the associated venous structures.[3,5,8,9] The part of the FV in the mandibular region is particularly tortuous,[18] and the vascular structures between the SOV and the angular vein are very complex and not always visible,[4] making catheter advancement through this region challenging.[4,9,18] We were unable to pass through the section between the SOV and angular vein using the triple coaxial method in a case in which the access route was not confirmed on preoperative CTA or US.

The termini of the FVs differed from those seen during the dissection of CS-DAVFs.[9,10] Luo et al.[9] reported that 38% of FVs drained into the IJV, and the other 62% drained into the EJV, and Naito et al.[10] reported a case in which the FV flowed into the subclavian vein and was not connected to the IJV. In contrast, in our patient 4 the FV terminated at the brachiocephalic vein via the ITV. In cases of successful catheterization of CS-DAVFs via the FV (including our patients), the FV drained into the IJV or EJV.[3,9,17] On the other hand, Naito et al. failed to access the CS via the FV, which flowed into the subclavian vein without connecting to the IJV.[10] In our study, catheterization of an FV that drained into the brachiocephalic vein was also impossible due to the instability of the guiding catheter. Whether the FV flows into the IJV or EJV might be an important factor affecting the success of catheterization during trans-FV TVE for CS-DAVFs.

CTA enables the wide-ranging acquisition of images with high spatial resolution due to the high number of slices it provides. 3D reconstruction on a workstation makes it easier to understand the relationships between the drainage route and surrounding structures, such as the skull, cervical vertebrae, and clavicle. In patient 4, a microcatheter was guided to the ITV under the support of intraoperative radioscopy and a roadmap by examining the outflow from the ITV to the brachiocephalic vein in multiple directions on preoperative CTA. In the present study, we found that compared with DSA, CTA depicted the drainage route more clearly, especially in the cervicothoracic region, and was also more helpful during the insertion of catheters into the FV.

Due to the superficial locations of the anterior drainage routes of some CS-DAVFs, US-guided direct puncture of the FV might be a feasible alternative when performing TVE via the femoral vein is difficult.[9,11] The route of the SOV can also be confirmed on US.[19] In our patients, US provided information about flow dynamics and blood vessel diameter along the entire drainage route from the SOV to the cervical region. Some portions of the drainage route that could not be visualized on CTA, such as the periorbital and mandibular sections, were confirmed in detail using US. In patient 2, blood flow signals were detected from the SOV to the angular vein on US, and trans-FV TVE was successful. On the other hand, in patient 3, the blood flow signals from the SOV to the angular vein were unclear on US, and it was difficult to pass a microcatheter through this region. We found that US is a useful tool for confirming the feasibility of trans-FV TVE, especially in the periorbital region. When performing trans-FV TVE for a CS-DAVF, detecting blood flow through the periorbital drainage pathway on US indicates that it should be possible to access the CS-DAVF via the FV, even if the periorbital drainage pathway cannot be confirmed on CTA. However, our findings suggest that access via the FV becomes more challenging when blood flow through the periorbital drainage pathway cannot be confirmed on US.

We could not access CS-DAVFs via occluded FVs using the triple coaxial method in patients in whom the entire anterior drainage route was confirmed to be patent on preoperative CTA and US 8 days before the procedure. Although it is often possible to perform TVE for CS-DAVFs via occluded IPSs,[7,8] Biondi et al.[4] reported that it was difficult to navigate through thrombosed SOVs. As the trans-IPS approach is a short and straight access route to the CS, while the FV is a tortuous, long pathway containing various structures,[3,5,8,9] it might be difficult to catheterize thrombosed FVs, even using the triple coaxial method, due to the lack of supporting force. In cases in which the route of the anterior outflow tract is confirmed on preoperative CTA or US and trans-FV TVE is planned, if the anterior outflow tract is found to be thrombosed on intraoperative imaging, a change in the access route should be considered.

The present study was limited by the fact that it involved a very small number of patients (n = 5). Greater numbers of patients must be examined.

Conclusion

The results of our retrospective analyses demonstrated the usefulness of preoperative CTA and US for confirming the anterior access route for trans-FV TVE for CS-DAVFs and predicting the feasibility of such procedures. Our findings suggest that detecting blood flow on US should enable CS-DAVFs to be accessed via the FV, even when the periorbital drainage pathway cannot be confirmed by CTA, but achieving this becomes more challenging when blood flow cannot be detected on US.

Disclosure Statement

All authors declare no conflict of interest.

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