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ORIGINAL RESEARCH
NEUROINTERVENTION

Dural arteriovenous fistulas involving the superior sagittal and parasagittal sinuses: clinical presentation, imaging characteristics and treatment strategies

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ABSTRACT

BACKGROUND AND PURPOSE: Dural arteriovenous fistulas (DAVFs) involving the superior sagittal (SSS) and parasagittal sinuses are often inappropriately classified. We explore the clinical presentations, imaging characteristics and endovascular treatment strategies of these two DAVF subtypes.

MATERIALS AND METHODS: Clinical and imaging data of 19 patients with SSS or parasagittal sinus DAVFs who underwent endovascular treatment in our institution from 2017 and 2022 were retrospectively analyzed. The angiographic findings, endovascular treatment strategies and angiographic outcomes were evaluated and recorded.

RESULTS: Among these 19 patients, 14 had a parasagittal DAVF, 4 had a SSS DAVF, one patient had both a parasagittal and SSS DAVF. Only one (1/19, 5.26%) patient presented with intracranial haemorrhage (ICH); For the parasagittal DAVF group, most of the shunts were located along the middle third of the SSS (12/15, 80%), on the dura in proximity with the junctional zone between the bridging vein and SSS (15/15, 100%), with ipsilateral cortical venous reflux (CVR) (15/15, 100%). For the SSS DAVF group, all 5 patients had shunting zone along the middle third of the SSS, on the sinus or parasinus wall, with bilateral CVR. Trans-arterial embolization, via the middle meningeal artery (MMA) as the primary route of access, was the primary treatment approach in 95% of cases (19/20). Reflux of embolization material into the SSS was observed in one case (1/5, 20%) of SSS DAVF in which balloon sinus protection was not used during embolization.

CONCLUSIONS: Our study found that parasagittal DAVFs have shunting point(s) centred on the junctional zone of the bridging vein and the SSS with ipsilateral CVR, while SSS DAVFs have shunting point(s) centred on the sinus or parasinus wall with bilateral CVR. Trans-arterial embolization via the MMA(s) can be used as the primary treatment strategy in most cases. Balloon sinus protection during embolization is not necessary in cases of parasagittal DAVF with occluded or stenosed connection with the SSS but its use should be considered in cases of SSS DAVF with patent sinus.

ABBREVIATIONS: DAVF, Dural arteriovenous fistula; SSS, Superior sagittal sinus; CVR, Cortical venous reflux; MMA, middle meningeal artery; ICH, Intracranial haemorrhage; STA, Superficial temporal artery; OA, Occipital artery. CFD, Computational fluid dynamics.

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SUMMARY SECTION

PREVIOUS LITERATURE: Dural arteriovenous fistulas (DAVFs) are abnormal arteriovenous shunts located on or between the layers of the dura matter. Sinus thrombosis, infection, trauma, or surgery may be present preceding the formation of DAVFs. Venous hypertension has been hypothesized to be the key factor triggering the formation of DAVFs by increasing the expression of hypoxia-inducible factor-1 (HIF-1) and vascular endothelial growth factor (VEGF) leading to angiogenesis. SSS-DAVFs and parasagittal DAVFs are often loosely classified under the umbrella terms "SSS-DAVFs, Convexity-DAVFs or Falx-DAVFs".

KEY FINDINGS: Parasagittal DAVFs are non-sinus-type fistulas with shunting point(s) centred on the junctional zone of the bridging vein and the SSS leading to ipsilateral CVR, while SSS DAVFs are sinus-type fistulas with shunting point(s) centred on the sinus or parellel parasinus wall with bilateral CVR.

KNOWLEDGE ADVANCEMENT: Trans-arterial embolization using liquid embolic material via the MMA(s) can be used as the primary treatment strategy in most cases of parasagittal and SSS DAVFs. The use of balloon sinus protection is not necessary in most cases of parasagittal DAVF but likely to be required in SSS DAVFs.

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INTRODUCTION

Dural arteriovenous fistulas (DAVFs) are abnormal arteriovenous shunts located on or between the layers of the dura matter. DAVFs are uncommon, with the reported detection rates of up to 0.5 per 100,000 adults per year [1,2].

Sinus thrombosis, infection, trauma, or surgery may be present preceding the formation of DAVFs. Thus, venous hypertension, with or without venous cerebral ischaemia, has been hypothesized to be a key factor triggering the formation of DAVFs, by increasing the expression of hypoxia-inducible factor-1 (HIF-1) and vascular endothelial growth factor (VEGF) leading to angiogenesis [3,4].

DAVFs most commonly involve the transverse - sigmoid sinuses and cavernous sinuses, with superior sagittal sinus (SSS) involvement seen only in up to 5% of DAVF cases. SSS-DAVFs and parasagittal DAVFs are often indistinguisably classified under the umbrella term of "SSS-DAVFs, Convexity-DAVFs or Falx-DAVFs". SSS-DAVFs are sinus-type fistulas with shunt point(s) on the dura surrounding the sinus or parasinus wall, while parasagittal DAVFs are non-sinus-type fistulas with shunt point(s) on the dura matter in close proximity to the dural penetration of the bridging vein[5]. In sinus-type DAVF, the sinus is often progressively compartmentalized and may eventually occlude, leading to cortical venous reflux (CVR) and congestion. In non-sinus-type DAVF, on the other hand, there is direct drainage to the cortical veins and thus invariably CVR [5].

Both SSS-DAVF and parasagittal-DAVF are prone to aggressive clinical symptoms as they often have direct or indirect CVR. The reported presenting symptoms include weakness, numbness, headache, seizures, visual symptoms, less frequently dementia, gait disturbance, aphasia and tinnitus. Based on a literature review of 31 cases of SSS DAVF in 20 publications, up to 42% of patients presented with intracranial haemorrhage (ICH) [6].

In this retrospective review of a single centre cohort study, we aimed to explore the clinical presentations, imaging characteristics and endovascular treatment strategies of these two (SSS vs parasagittal) DAVF subtypes. Specific imaging features differentiating these two distinct entities were analysed to help with disease categorization. The clinical implications of differentiating these two DAVF subtypes including potential procedural complications and the need for sinus balloon protection during embolization are discussed in this study.

MATERIALS AND METHODS

We conducted a retrospective analysis of a prospectively collected vascular malformation database after institutional ethics board approval. We identified all cases of dural arteriovenous fistulas treated endovascularly between January 2017 and December 2022. The subgroups of patients diagnosed with SSS or parasagittal DAVF were selected and included in this review.

Age, sex, clinical presentation, angiographic findings, treatment strategies, angiographic, and clinical outcome and complications were reviewed and recorded in an anonymized manner. Pre-treatment six-vessel biplane catheter angiography with selective cannulation of bilateral internal carotid arteries (ICAs), external carotid arteries (ECAs), and vertebral arteries was performed in all patients prior to treatment for evaluation of the angioarchitecture. DAVFs were categorized according to the Borden classification (Types I-III) and Cognard classification (Type I-V). Endovascular treatment was considered the primary treatment option in all cases after initial angiographic assessment. Endovascular techniques, including arterial access (and venous access in some cases), embolization vessel selection and techniques, the use of balloon for dural sinus protection, immediate angiographic outcome and peri-procedural complications (up to 30 days post-procedure) were recorded. Imaging follow-up after treatment was obtained with either magnetic resonance angiography (MRA), digital subtraction angiography (DSA) (or both), or computed tomography angiography (CTA).

Ethical Aspects

This study obtained ethics approval from the research ethics board of the University of Toronto with ID-number 19-5018.4. Informed consent requirement was waived owing to the retrospective nature of the study.

RESULTS

Clinical and Imaging Characteristics

Of 155 patients with DAVF managed in our institution between 2017 and 2022, 19 patients (12.3%) were identified with a parasagittal or SSS DAVF. Among these 19 patients, 14 had a parasagittal DAVF, 4 had a SSS DAVF, one patient had both a parasagittal and SSS DAVF. The patient with both parasagittal and SSS DAVF had two distinct DAVFs centred at two separate segments – mid parasagittal and posterior SSS segments respectively and was treated in two separate sessions. Tables 1 and 2 (Supplementary Table 1 and 2) summarize the clinical and imaging characteristics of patients with parasagittal DAVF and SSS DAVF.

For the group of patients with parasagittal DAVF, the two most common clinical presentations were headaches (6/15, 40%) and pulsatile tinnitus (5/15, 33.33%). Only one (1/15, 6.67%) patient presented with ICH. Most (12/15, 80%) of the shunts were located along the middle third of the SSS, and in all cases (15/15, 100%) the fistulous points were located on the dura in proximity to the junctional zone between the bridging vein and SSS. Middle meningeal artery (MMA) feeders were present in all (15/15, 100%) cases, followed by occipital artery (OA) and superficial temporal artery (STA) feeders (10/15, 66.67%). Unilateral CVR, ipsilateral to the side of fistula, was present in 15/15 cases (100%). All fistulae were classified as Borden Type III and Cognard type IV fistulae.

For the group of patients with SSS DAVF, visual disturbance was one of the main presenting symptoms (2/5, 40%). None of the patients presented with ICH. All 5 patients had preceding trauma to the vertex or underlying dural venous sinus thrombosis. All 5 patients had the shunting zone located at the middle third of the SSS, with the fistulous points on the sinus or parasinus wall. MMA, OA and STA feeders were present in all 5 cases of SSS DAVF. All 5 cases of SSS DAVF were of Borden type II, 4 cases (80%) of Cognard type IIa+b and 1 case (20%) of Cognard type IIa. Bilateral CVR was observed in all 5 cases.

Table 1: Clinical characteristics of patients with parasagittal DAVF and SSS DAVF.

Variables	Parasagittal DAVF (n=15*)	SSS DAVF (n=5*)
Mean age at diagnosis (range)	63.2 (46-86)	58.2 (36-79)
Sex (female)	4 (26.67%)	1 (20%)
ICH at presentation	1 (6.67%)	0
Underlying precipitating factors		
Trauma	1 (6.67%)	3 (60%)
Thrombosis	0	2 (40%)
None	14 (93.33%)	0

*1 patient with both parasagittal and SSS DAVFs was included in both the parasagittal DAVF and SSS DAVF groups.

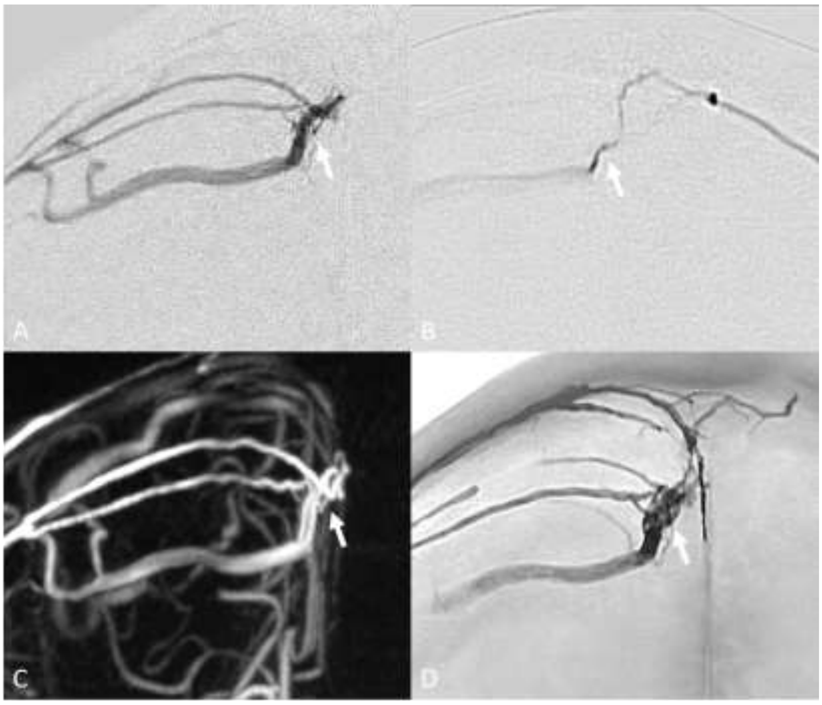

FIG 1. 83-year-old male with right parasagittal DAVF. A-C. Digital subtraction angiography (DSA), frontal view. D. Non-subtracted fluoroscopic image. A-C. Arterial feeders from the right MMA and left MMA are centred on the junctional zone of the cortical bridging vein entering the SSS (fistulous point, arrow) with ipsilateral CVR. D. Transarterial Onyx embolization via the right MMA is evidenced by formation of Onyx cast along bilateral MMA arterial feeders and the diseased cortical vein.

Embolization Procedures

Table 3 (Supplementary Table 3) summarizes the treatment and outcomes of patients with parasagittal DAVF and SSS DAVF.

Arterial access was obtained via trans-femoral or trans-radial approaches. Venous access, if required, was done via trans-femoral or trans-jugular approaches. Typically, a 5F to 8F guiding catheter was used, depending on vascular tortuosity and treatment approach.

Trans-arterial embolization was used as the endovascular treatment approach in all cases of parasagittal DAVF (15/15, 100%) and all except for one of the SSS DAVF cases (4/5, 80%).

Trans-arterial embolization with liquid embolic materials (typically Onyx, Covidien/ev3, Irvine, CA, USA) was performed using either flow-directed microcatheters (with or without detachable tip), dual lumen balloon microcatheters or employing pressure-cooker techniques by navigating a second microcatheter more proximally to the same branch to build up a plug with coils and/or glue. The arterial access route for embolization was decided based on vessel tortuosity and the size of the vessels; Dural (rather than trans-osseous) arterial feeder with straighter course and larger diameter was first chosen for embolization due to the ease of catheter navigation. Injection of liquid embolic material was performed to occlude the fistulous point and the adjacent distal arterial feeders. Injection was stopped as soon as the liquid embolic material reaches the foot of the vein or sinus wall, to minimize excessive reflux to the veins or sinus, especially if the veins or sinus are still used by the brain for normal venous drainage, to avoid venous thrombosis and propagation. Contrast opacification of the diseased vein or sinus only on the arterial phase but not the normal venous phase of the angiogram was indicative of its non-functioning status (Fig. 1 and Fig. 2).

Balloon sinus protection during embolization was performed in 2/15 (13.33%) of parasagittal DAVF cases and 2/5 (40%) of SSS DAVF cases. 3/5 (60%) of SSS DAVF cases in our series had embolization without balloon sinus protection; one had severely stenosed SSS caused by depressed skull fracture, one had chronically thrombosed SSS, and the other one had patent SSS but with challenging venous access (occluded right transverse sinus and hypoplastic left transverse sinus).

The only case treated by a transvenous approach was performed on a patient with SSS DAVF (Fig. 3). The fistulous point was centred on a single channel of a bifurcated SSS. Liquid embolic embolization of the diseased sinus channel was performed under balloon protection of the dominant sinus channel.

Table 2: Imaging characteristics of patients with parasagittal DAVF and SSS DAVF.

Variables	Parasagittal DAVF (n=15*)	SSS DAVF (n=5*)
Shunt location		
Middle third of SSS	12 (80%)	5 (100%)
CVR (relation to shunt)		
Ipsilateral	15 (100%)	0
Bilateral	0	5 (100%)
Arterial feeders		
MMA	15 (100%)	5 (100%)
STA or OA	10 (66.67%)	5 (100%)
Pial-dural supply	7 (46.67%)	4 (80%)

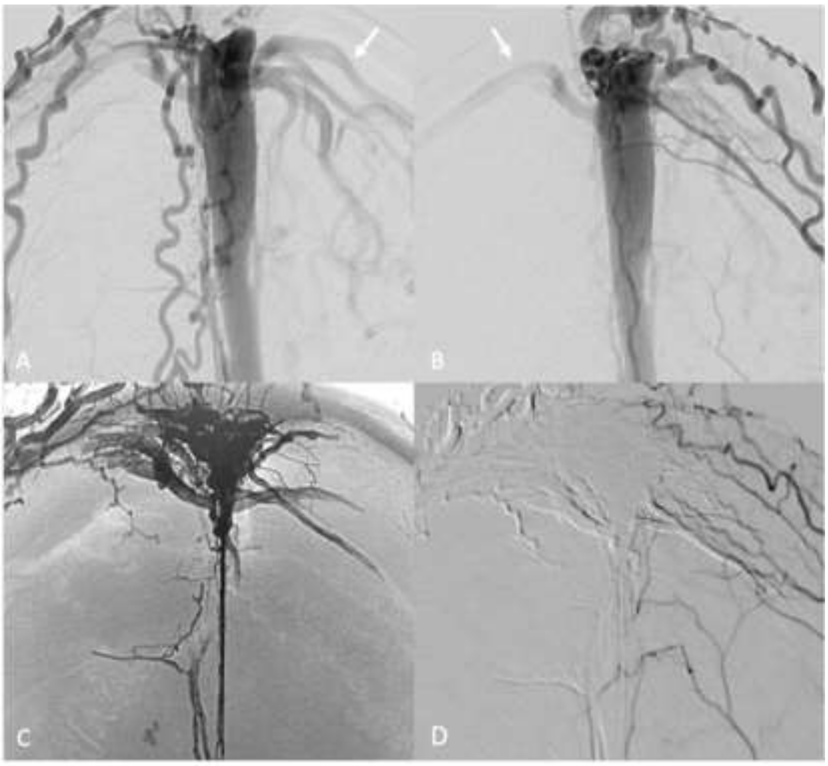

FIG 2. 34-year-old female with SSS DAVF. A-B, D. Digital subtraction angiography (DSA), frontal view. C. Non-subtracted fluoroscopic image. A, B. Arterial feeders from the trans-osseous branches of bilateral OAs and STAs, left MMA, bilateral posterior meningeal arteries, arteries of Davidoff and Schechter, right anterior falcine artery and left pericallosal pial-dural branch (not shown). The fistulous points are centred on the wall of the patent SSS, with extensive bilateral CVR (arrows) due to occluded right transverse sinus and hypoplastic left transverse sinus, precluding the use of balloon sinus protection. The SSS is used solely for fistulous drainage. C. Three sessions of staged trans-arterial embolization, with Onyx cast formation along the sinus wall, the arterial feeders and the draining cortical bridging veins. There is evidence of Onyx reflux into the SSS, non-occlusive. D. Post-embolization angiogram confirms complete occlusion of the DAVF.

Angiographic Outcome

Arterial feeders from the MMA (unilateral or bilateral) were present in all cases of parasagittal and SSS DAVF. For all cases of parasagittal DAVF, trans-arterial embolization with liquid embolic material via the MMA was attempted as the primary treatment approach. With this approach, complete angiographic occlusion was achieved in 93.33% (14/15) of parasagittal DAVF cases. A single case (6.67%, 1/15) of parasagittal DAVF required additional embolization via the STA feeder during the same session, rendering total complete angiographic occlusion after the first embolization session at 100% (15/15). Imaging follow-up was performed in 93.33% (14/15) of patients with parasagittal DAVF, with 73.33% (11/15) of patients had DSA follow-up, and overall mean imaging follow-up duration of 11 months. Recurrence on follow-up angiogram was detected in two patients. One was re-treated successfully with repeat embolization which remained occluded with no recurrence at 2 years follow-up while the other patient who had both a parasagittal and SSS DAVFs had recurrence of the parasagittal DAVF and was not re-treated in view of minimal fistulous flow in an asymptomatic patient who is still recovering from scalp necrosis (result of liquid embolic reflux to the scalp vessels from embolization of SSS DAVF).

For cases of SSS DAVF, complete angiographic occlusion was achieved in 2 patients after the first treatment session (2/5, 40%). For complex SSS DAVF cases, staged embolization was anticipated by the operators with primary target of embolization pre-determined prior to each session. One patient required a total of 3 staged embolization sessions to achieve complete angiographic occlusion while the other patient had complete occlusion after 2 staged embolization sessions with subsequent recurrence, requiring 3 additional embolization treatment sessions (a total of 5 treatment sessions). One patient had residual fistula fed by the anterior falcine artery, with resolution CVR

Table 3: Treatment and angiographic outcome of patients with parasagittal DAVF and SSS DAVF.

Variables	Parasagittal DAVF (n=15*)	SSS DAVF (n=5*)
Treatment approach		
Trans-arterial	15 (100%)	4 (80%)
Trans-venous	0	1 (20%)
Balloon protection		
Yes	2 (13.33%)	2 (40%)
No	13 (86.67%)	3 (60%)
Number of treatment sessions to achieve complete occlusion (mean)	1	2.4

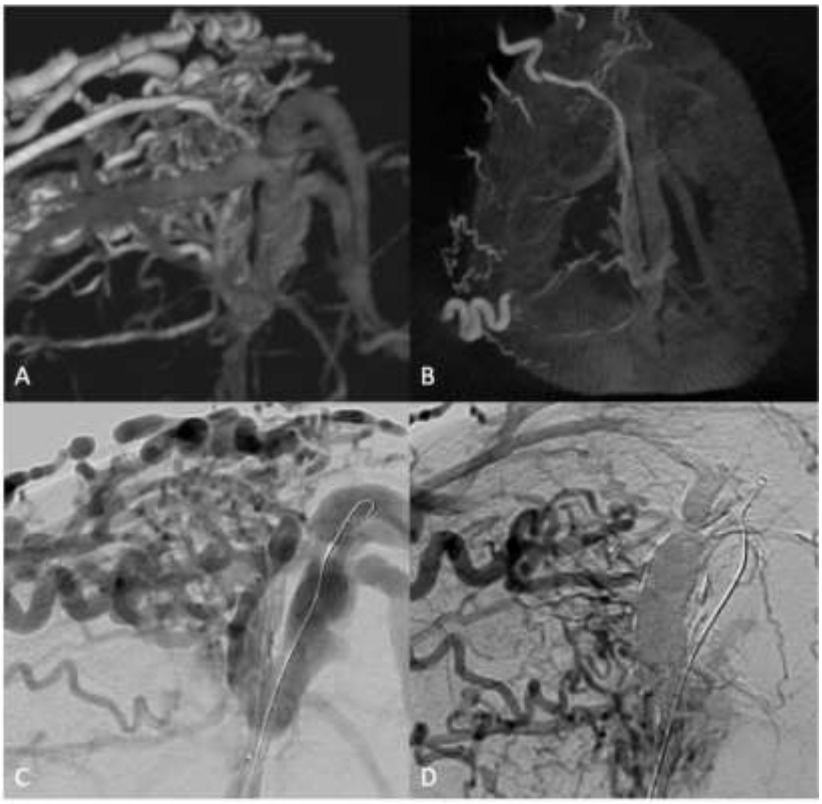

FIG 3. 75-year-old male with SSS DAVF with variant morphology. A, C-D. Digital subtraction angiography (DSA), frontal view. B. Axial CT reconstruction from spin angiography. A-C. Variant anatomy of SSS – split channel / unfused segment. The arterial feeders from bilateral MMAs, OAs and STAs centred on the wall of the right para-midline channel of SSS, with bilateral CVR. D. Single session of trans-venous Onyx embolization under balloon protection of the left paramidline channel of SSS resulting in complete occlusion of DAVF.

and clinical symptoms, not planned for further embolization. Imaging follow-up with DSA was performed in all 5 patients, with mean follow-up duration of 7.6 months. 4/5 (80%) patients eventually achieved complete angiographic occlusion with no recurrence on final follow-up imaging.

Clinical outcome and procedural complications

All patients in both parasagittal and SSS DAVF groups had improvement or resolution of clinical symptoms post embolization.

In the parasagittal DAVF group, one patient had a technical complication of a retained distal segment of a microcatheter (proximal to the detachable tip) in the external carotid artery following liquid embolic (Onyx) embolization via the MMA, with no clinical consequence. Another patient had inadvertent extra-vascular Onyx leakage surrounding the SSS during trans-arterial liquid embolic embolization via the MMA, which resulted in a thin (2mm) subdural haematoma along the falx, with no clinical deficits and complete resolution on subsequent follow-up.

In the SSS DAVF group, two patients experienced scalp necrosis post-embolization, attributed to penetration of liquid embolic materials to the scalp arterial feeders. One healed rapidly without infection while the other experienced a large area of occipital scalp necrosis complicated with infection and abscess formation requiring drainage and antibiotics. The latter patient had both parasagittal DAVF and SSS DAVF in two separate segments. He was treated initially for the parasagittal DAVF without complications. The SSS DAVF subsequently transformed into higher grade (Borden II) fistula which prompted treatment. Following pressure-cooker techniques via two occipital arterial feeders under balloon sinus protection, complete angiographic occlusion was achieved in a single session. However, the patient developed scalp necrosis post procedure with superimposed infection required drainage. One patient with challenging venous access and patent SSS who underwent transarterial embolization without balloon sinus protection, had reflux of Onyx into the SSS, non-occlusive with no clinical implication.

DISCUSSION

In this retrospective study of 19 patients with 15 parasagittal DAVF and 5 SSS DAVF, our patient cohort has a mean age of 5th to 6th decades with male predominance, similar to the findings of the published meta-analysis on SSS DAVF [6]. Different from the published meta-analysis that demonstrated a high rate (up to 42%) of intracranial haemorrhages [6], in our series we found a relatively low haemorrhagic rate (1/19, 5.26%). The exact reason for this discrepancy in haemorrhagic presentation is unclear and may be attributed to publication bias, small number of patients given its rarity and increased detection rates in recent years with higher prevalence rates of imaging for non-specific symptoms. Nevertheless, active treatment is recommended in all cases of parasagittal DAVF (Borden type III) and in most cases of SSS DAVF (Borden type II) given their inherent risk of subsequent neurological deterioration and risk of haemorrhage.

In our study, we categorized our patients into two groups depending on the location of the shunt: – parasagittal DAVF and SSS DAVF. Patients with parasagittal DAVF had their fistulous point(s) on the dura matter in close proximity to the dural penetration of the bridging vein (Fig. 1). Patients with SSS DAVF, on the other hand, had their fistulous point(s) more medially on the dura surrounding the sinus wall (Fig. 2) or parallel parasinus channel (Fig. 3). In our study, we observed that in parasagittal DAVF, venous reflux was seen primarily along the cortical veins ipsilateral to the shunt point (as parasagittal bridging veins are limited by the dura propria that are adhered back-to-back along midline) and secondarily into the SSS in the presence of patent connection. In SSS DAVF, venous reflux was seen primarily along the SSS, with presence of cortical venous reflux bilaterally in higher grade fistula.

For parasagittal DAVFs, we found that the most common site of fistulous connection lies adjacent to the middle segment of the SSS. This occurrence may be explained by the following anatomical considerations. The bridging veins draining into the SSS are smaller in calibre along the anterior third of the SSS, and larger in calibre along the middle third of the SSS [7]. Bridging veins join the middle segment of the SSS predominantly in a perpendicular or retrograde fashion (ie <90 degree angle), while an antegrade course (or >90 degree angle) is more commonly observed in the anterior segment [8,9]. Haemodynamic assessment using computational fluid dynamics (CFD) based on bridging vein physical models demonstrated higher tendency for formation of thrombosis within the bridging vein when the diameter of a bridging vein is greater than 1.2 mm and the entry angle is less than 65° (retrograde course) due to significantly reduced wall shear stress (WSS) [10]. Low WSS causes sharp reduction of the anticoagulant substance, enhancement of leukocyte adhesion and proliferation of smooth muscle which can lead to thrombosis. In addition, bridging veins in the middle segment of the SSS more often found with hairpin loops or lacunae [8,9] with flow turbulence and stagnation, increasing the propensity for thrombus formation [11]. WSS in the bridging vein wall reduces more significantly (hence increase propensity for thrombus formation) compared to the SSS wall, which may explain the higher incidence of parasagittal DAVF (than SSS DAVF) in our cohort.

In all cases (15/15, 100%) of parasagittal DAVF, the fistulous points were located in proximity to the junctional zone between the cortical vein and the SSS, which, according to the CFD hemodynamic assessment described above, is the predilection site of cortical vein thrombosis [10]. The predilection for occlusion of the junctional zone between cortical vein and the SSS is supported by the anatomy (change in calibre) and histology of the bridging vein at the junctional zone. There is focal dilatation followed by narrowing ("puffy vein appearance") prior to the confluence of cortical veins with the SSS [7]. The collagen fibres of the distal cortical vein are densely packed along its subarachnoid course with longitudinally oriented fibres, but only loosely webbed along its subdural course leading to the junctional zone with the SSS, with circumferentially oriented fibres (constricted cuff segment) just proximal to its confluence with the SSS [9]. These abrupt changes in calibre and histology may lead to flow disturbance, thrombus formation and subsequent DAVF development. These features may be accentuated with arterialization as dilatation of the cortical vein may promote further narrowing of this sphincter mechanism (Fig. 1) leading to occlusion of the junction between the cortical vein and the SSS. Thus, we hypothesize that both a primary thrombotic occlusion of the junctional zone between the cortical vein and the SSS and the primary arterialization of a bridging vein may explain the imaging features of parasagittal SSS dAVF with a fistula location at the junction between the cortical vein and the SSS as well as a missing or narrowed connection between these two venous structures.

Bridging vein thrombosis can be clinically silent due to abundant collateral circulation whereas SSS thrombosis causes backflow obstruction of all draining veins before the lesion location thus being more commonly clinically symptomatic [10]. In our study, the majority (14/15, 93.3%) of the cases of parasagittal DAVF had no precipitating aetiology, while all (5/5, 100%) patients with SSS DAVF had either prior trauma with skull fractures causing dural venous sinus stenosis or preceding dural venous sinus thrombosis. These conditions can lead to venous hypertension and can cause an increase in angiogenic growth factors which have been found to be related to the formation of DAVF.

In terms of treatment strategy, MMA arterial feeders were the primary route for trans-arterial embolization. With this treatment approach, complete angiographic occlusion was achieved in 93.3% (14/15) of parasagittal DAVFs. Balloon protection of SSS during trans-arterial embolization of parasagittal DAVF was infrequently used and as highlighted by the anatomical considerations discussed above - in retrospect not deemed necessary. Reflux of liquid embolic material into the SSS during embolization was not observed in any of our cases as the connection between the cortical vein and the SSS was occluded or narrowed in all cases of parasagittal sinus DAVF. We therefore propose that in parasagittal DAVFs, balloon sinus protection of the SSS during embolization, especially in cases of occluded or narrowed connection with the SSS, is not required. We observed no permanent complications for the treatment of parasagittal sinus DAVF.

On the other hand, in SSS DAVF, more complex treatment strategies involving multiple treatment sessions or transvenous approaches, as well as complications (scalp necrosis) may be encountered. Based on our experience, the risk of developing scalp necrosis following embolization would depend on the amount of reflux of embolic material into the scalp arteries and the formation of collaterals to the affected scalp region. Tight band application over the scalp has been performed in a small number of patients in other centre to prevent excessive reflux of embolic materials, although its use has yet to be validated. As the shunting zone is located on the sinus wall with direct drainage to the SSS, we used balloon sinus protection in 2/5 (40%) of our SSS DAVF cases, thus preventing reflux of embolic material into the SSS. Balloon sinus protection was not used in the other 3/5 (60%) of our SSS DAVF cases due to occluded or stenosed SSS in 2/5 (40%) of the cases and due to challenging venous access with occluded right transverse sinus and hypoplastic left transverse sinus in 1/5 (20%) of the cases. The patient with challenging venous access had patent SSS, and without balloon sinus protection, there was reflux of Onyx into the SSS (non-occlusive in this case). We thus believe that balloon sinus protection is an important strategy in treatment of SSS DAVF with patent sinus.

This study has limitations and inherent bias being a retrospective single-centre study. Even though our series is from a high-volume neurovascular unit the number of cases included in this study was limited. This shows that this is a rare pathology and therefore our results cannot be extrapolated to other lower-volume settings as such. A multicentre study with review of pooled data would be of value to validate our findings.

CONCLUSIONS

Our study found that the shunting point(s) of parasagittal DAVFs were centred on the junctional zone of the bridging vein and the SSS with ipsilateral CVR, while the shunting point(s) of SSS DAVFs were centred on the sinus or parellel parasinus wall with bilateral CVR. Trans-arterial embolization using liquid embolic material via the MMA(s) can be used as the primary treatment strategy in most cases. In cases of parasagittal DAVF (commonly seen with occluded or stenosed connection of the involved bridging vein with the SSS), or in cases of SSS DAVF with occluded or stenosed sinus, our results suggest that the use of balloon sinus protection during embolization is not necessary. On the other hand, SSS DAVFs with patent sinus are likely to require balloon protection as these cases typically require complex treatment strategies or staged embolizations to achieve complete cure.

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Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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SUPPLEMENTAL FILES

Table 2: Clinical characteristics of patients with parasagittal DAVF and SSS DAVF.

Variables	Parasagittal DAVF (n=15*)	SSS DAVF (n=5*)
Mean age at diagnosis (range)	63.2 (46-86)	58.2 (36-79)
Sex (female)	4 (26.67%)	1 (20%)
Clinical presentation		
Weakness	2 (18.75%)	1 (20%)
Seizures	4 (26.67%)	1(20%)
Headache	6 (40%)	1(20%)
Visual symptoms	2 (13.33%)	2(40%)
Cognitive decline	0	1(20%)
Gait disturbance	0	1(20%)
Pulsatile tinnitus	5 (33.33%)	1(20%)
Incidental	1 (6.67%)	0
ICH at presentation	1 (6.67%)	0
Underlying precipitating factors		
Trauma	1 (6.67%)	3 (60%)
Thrombosis	0	2 (40%)
None	14 (93.33%)	0

*1 patient with both parasagittal and SSS DAVFs was included in both the parasagittal DAVF and SSS DAVF groups.

Table 2: Imaging characteristics of patients with parasagittal DAVF and SSS DAVF.

Variables	Parasagittal DAVF (n=15*)	SSS DAVF (n=5*)
Shunt location		
Anterior third	2 (13.33%)	0
Middle third	12 (80%)	5 (100%)
Posterior third	1 (6.67%)	1 (20%)
Fistulous point		
Junctional zone of bridging vein and SSS	15 (100%)	0
Sinus or parasinus wall	0	5 (100%)
Direct connection to SSS		
Absent	12 (80%)	N.A.
Present (stenosed)	3 (20%)	N.A.
CVR (relation to shunt)		
Ipsilateral	15 (100%)	0
Bilateral	0	5 (100%)
Arterial feeders		
MMA	15 (100%)	5 (100%)
STA	10 (66.67%)	5 (100%)
OA	10 (66.67%)	5 (100%)
Pial-dural supply	7 (46.67%)	4 (80%)
Borden classification		
I	0	0
II	0	5 (100%)
III	15 (100%)	0
Cognard classification		
I	0	0
IIa	0	1 (20%)
IIb	0	0
IIa+b	0	4 (80%)
III	0	0
IV	15 (100%)	0
V	0	0

*1 patient with both distinct parasagittal and SSS DAVFs treated at two separate sessions was included in both the parasagittal DAVF and SSS DAVF groups.

**1 patient with SSS DAVF has fistulous points along both the mid and posterior segments of SSS.

Table 3: Treatment and angiographic outcome of patients with parasagittal DAVF and SSS DAVF.

Variables	Parasagittal DAVF (n=15*)	SSS DAVF (n=5*)
Treatment approach		
Trans-arterial	15 (100%)	4 (80%)
Trans-venous	0	1 (20%)
Balloon protection		
Yes	2 (13.33%)	2 (40%)
No	13 (86.67%)	3 (60%)
Number of treatment sessions to achieve complete occlusion (mean)	1	2.4
Final complete angiographic occlusion		

Yes	15 (100%)	4 (80%)
No	0	1 (20%)
Complications		
With clinical sequelae	0	2 (40%)
Clinical outcome (Symptoms improvement or resolution)	15 (100%)	5 (100%)
Follow-up imaging modality		
MRA only	2 (13.33%)	0
CTA only	1 (6.67%)	0
DSA +/- MRA/CTA	11 (73.33%)	5 (100%)
Lost to follow-up	1 (6.67%)	0
Imaging follow-up duration based on the latest scan (mean, range) in months	11.13, 3-24	7.6, 3-15
Recurrence after occlusion	2 (13.33%)	1 (20%)
Treatment for recurrence	1 (6.67%)	1 (20%)
Occlusion at latest follow-up	14 (93.3%)	4 (80%)

**1 patient with SSS DAVF has fistulous points along both the mid and posterior segments of SSS.