Tentorial Dural Fistulas: Endovascular Management and Description of the Medial Dural-Tentorial Branch of the Superior Cerebellar Artery

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ABSTRACT

BACKGROUND AND PURPOSE: TDAVF s are uncommon causes of spontaneous intracranial hemorrhage. A retrospective review of their management was performed after repeatedly observing a previously under-recognized medial dural-tentorial branch of the SCA.

MATERIALS AND METHODS: Thirteen patients were diagnosed with TDAVFs by CT/MR imaging and DSA during a 5.8-year period. Seven patients presented after intracranial hemorrhage. Twelve patients were treated endovascularly, and one, surgically.

RESULTS: Eleven TDAVFs were located in the midline (7 at the falx cerebelli and 4 at the torcular), and 2 were petrotentorial. All torcular TDAVFs were associated with sinus thrombosis and showed bidirectional drainage relative to the tentorium. No sinus thrombosis was seen in the falx cerebelli subtype, which drained infratentorially only, except in 1 patient who had had unrelated surgery previously. Venous drainage was directly to cortical veins except for 1 petrotentorial and 2 torcular TDAVFs. A branch of the SCA, the medial dural-tentorial artery, was observed in 5 midline TDAVFs. Its anatomy was defined with selective angiography. Endovascular therapy resulted in a cure in 5 and subtotal occlusion in 6, and staged treatment is ongoing in 1 patient. One patient was cured after surgery.

CONCLUSIONS: TDAVFs frequently cause intracranial hemorrhage and therefore warrant treatment. Endovascular therapy proved effective in this series, and arteriography was essential for understanding the various fistula subtypes and for treatment planning. We emphasize the importance of recognizing the medial dural-tentorial artery of the SCA with its characteristic course along the tentorium on angiography. This artery should be included in future anatomic descriptions of the cranial blood supply.

ABBREVIATIONS: AICA = anterior inferior cerebellar artery; ADS = artery of Davidoff and Schechter; DAVF = dural arteriovenous fistula; SCA = superior cerebellar artery; TDAVF = tentorial dural arteriovenous fistula

Dural arteriovenous fistulas account for 10%–15% of all intracranial vascular shunts.1 2 The TDAVF is a rare subgroup, constituting <4% of DAVFs.1 3 5 6 TDAVFs are most frequently diagnosed in middle-aged men,2 4 5 7 unlike DAVFs elsewhere, which are more frequent in elderly women.6 9 Spontaneous intracranial hemorrhage is the usual presenting symptom because cortical venous reflux is common.4 6 7 10 Otherwise, diagnosis relies on imaging because neurologic symptoms are nonspecific and nonlocalizing.6 11 12

TDAVFs are generally considered separate from DAVFs located along the transverse and sigmoid sinuses despite their proximity. This distinction appears to be historic and is based on anatomic, symptomatic, and therapeutic differences. Anatomically, DAVFs primarily involve the single-layer dura of the calvaria, while TDAVFs occur in the reflected (double-layer) dura of the tentorium and its attachments. Because TDAVFs usually drain to cortical veins, invasive treatment is recommended, irrespective of presentation.4 6 7 10 Treatment is traditionally by surgical resection but access is often difficult,10 and endovascular therapy is a recognized and increasingly used alternative, either alone or in combination with surgery.17 Another alternative is stereotactic radiosurgery, which has been reported in feasibility studies18 19 and may be a useful adjunct to endovascular treatment.

Due to their rarity, the number of reports describing TDAVFs and their management is limited. Nevertheless, several classification systems have been proposed on the basis of location and venous drainage patterns.5 7 The arterial supply is not an important feature in these descriptions, but with the increasing use of endovascular treatment, it is clearly important and may be helpful in classification and distinguishing TDAVFs from DAVFs located at the tentorial margins.

We present 13 TDAVFs and classify them according to location and overall vascular supply. Special attention is drawn to an
under-recognized medial dural-tentorial branch of the superior cerebellar artery, which has not been previously demonstrated by selective arteriography, to our knowledge. We describe the main features of this artery to emphasize its importance in future anatomic descriptions of TDAVFs.

PATIENTS AND METHODS

Patients

A search of our institutional data base identified 13 patients with TDAVFs presenting between January 2007 and September 2012. DAVFs of the transverse or sigmoid sinuses and other posterior fossa locations not supplied by tentorial arteries were excluded. All patients underwent initial CT/CTA and/or MR imaging/MRA, as well as subsequent DSA before treatment. The mean age was 59.8 years (age range, 45–66 years) with a male/female ratio of 8:5 (Table 1).

Presentation

Symptoms were the following: headache (n = 7), tinnitus (n = 2), visual disturbances (n = 3), transient weakness (n = 1), and progressive confusion (n = 1). One patient presented after imaging for coincidental stroke. Seven patients presented after spontaneous intracranial hemorrhage; 3 were initially unconscious, requiring mechanical ventilation. Imaging showed posterior fossa hemorrhage; principally subarachnoid in 4, cerebellar in 3, with intraventricular hemorrhage in 4 patients (Table 1).

Angiographic Findings

TDAVFs were classified by the arteriovenous shunt location (Fig 1). Most were midline and could be separated into torcular (n = 4) (Figs 2 and 3) and falx cerebelli (n = 7) (Figs 4 and 5). The remaining 2 fistulas were at lateral petrotentorial locations along the petrous attachment of the tentorium. All drained to subarachnoid/cortical veins and were classified as type III or IV fistulas, except I petrotentorial and 2 torcular fistulas that were graded type II a + b according to Cognard et al.20 In 2 of the torcular fistulas, bilateral occlusion of the lateral/sigmoid sinuses was present, and in the other 2, complete or partial thrombosis of 1 lateral sinus was evident (Table 2).

The arterial supply demonstrated on DSA is detailed in Table 1). One patient presented after imaging 3), transient weakness (n = 1), and progressive confusion (n = 1). One patient presented after imaging for coincidental stroke. Seven patients presented after spontaneous intracranial hemorrhage; 3 were initially unconscious, requiring mechanical ventilation. Imaging showed posterior fossa hemorrhage; principally subarachnoid in 4, cerebellar in 3, with intraventricular hemorrhage in 4 patients (Table 1).

FIG1. Sites of TDAVFs: 1 = falx cerebelli, 2 = torcular, and 3 = petrotentorial locations.

No. Age (yr) Sex Clinical Presentation Initial CT/MR
1 45 M Collapse, headache CT/CTA: ICH posterior fossa, developing hydrocephalus
2 64 M Unrelated stroke, incidental finding on imaging CT/CTA: small subacute ischemic area supratentorially, dilated abnormal vessels in the posterior fossa
3 56 M Collapse, vomiting, dysarthria, blurred vision CT/CTA: ICH posterior fossa, developing hydrocephalus
4 65 F Transient arm weakness MRI: abnormal vessels with venous engorgement
5 65 M Acute-onset headache MRI: abnormal vessel structures in the right-side posterior fossa
6 64 F Hearing loss, tinnitus, diplopia CT/CTV: engorged leptomeningeal veins
7 64 F Headache, progressive mental confusion, dysphasia MRI: multiple congested intracranial veins
8 66 M Visual disturbance and hemianopia CT/CTA: posterior fossa SAH
9 58 M Acute-onset headache CT/CTA: posterior fossa SAH
10 60 F Severe headache, vertigo CT: perimesencephalic SAH
11 64 M Collapse, vomiting, aphasia CT: posterior fossa SAH with intraventricular spread
12 56 F Pulsatile tinnitus MRI: abnormal vessels
13 60 M Acute-onset headache CT: cerebellar ICH

Note:—CTV indicates venous phase CTA.
inferiorly, from anterior to posterior, while the more inferiorly lying medial dural-tentorial artery of the SCA has a more horizontal posterior course toward the midpoint of the inferior surface of the straight sinus. Both arteries turn medially posterior to the tentorial hiatus and run toward the midline (Figs 2–5).

None of the fistulas showed supratentorial venous drainage only. The fistulas at the falx cerebelli drained inferiorly to the posterior fossa veins in all cases and additionally to the supratentorial cortical veins in 1 patient. The 4 lesions at the torcular drained to tentorial veins and then to both infra- and supratentorial cortical veins. The petrotentorial fistulas drained to cortical veins above and below the tentorial attachment in 1 patient and only infratentorially in 1 patient (Table 2).

FIG 2. Torcular TDAVF (patient 8). Injections of the right vertebral artery in the lateral (A) and anteroposterior (B) views. Note the medial dural-tentorial branch of the left SCA (white arrow) running below the ADS (black arrow); both arteries are supplying the fistula. Additional supply is seen from the posterior meningeal artery and muscular branches of the extracranial vertebral artery.

FIG 3. Torcular TDAVF (patient 7). Injections into the left vertebral artery in lateral (A) and the right vertebral artery in lateral-oblique (B) views show the supply to the fistula from the left ADS (black arrows) and the left medial dural-tentorial branch of the SCA (white arrows). There was additional arterial supply from branches of the external carotid artery (not shown).

Endovascular Treatments

Endovascular therapy was performed in 12 patients (1 after fistula recurrence following surgery), and 1 patient was treated by surgery after failed endovascular therapy. Endovascular therapy was performed as single treatments (7 patients) or staged (3 patients underwent 2, and 2 patients 3) treatments. Access was transarterial in 10 or transvenous and transarterial in 2 patients. Embolization was performed with either ethylene-vinyl alcohol, formulated as Onyx (ev3, Irvine, California) or n-butyl cyanoacrylate formulated as Glubran (GEM, Viareggio, Italy). Onyx was used alone in 5, in combination with Glubran in 3, and with coils in 2 patients. Adjuvant coils were used transarterially to reduce blood flow and transvenously to occlude a large venous pouch in treatments of torcular and petrotentorial TDAVFs, respectively. Glubran was used alone to occlude an arterial aneurysm after SAH in 1 patient.

Procedural complications occurred during 4 endovascular treatments, without causing new symptoms or disability. They comprised 1 arterial dissection, 1 perforation (managed by sealing with Glubran), and 2 microcatheter ruptures (1 without vessel damage and 1 causing Onyx efflux and occlusion of the distal occipital artery) (Table 3).

Treatment Results

Anatomic. Endovascular therapy achieved complete occlusion of the fistula in 5 and subtotal occlusion in 6 patients. One patient is still in treatment, and the remaining patient (who was treated surgically) was cured (Table 4).

Clinical. Symptoms resolved completely in 3, improved in 6, and are unchanged in 1 patient. Two patients died due to other complications. One patient died 2 weeks after complete occlusion of the fistula due to malignant cerebellar swelling causing brain stem compression despite decompression occipital craniectomy to remove the presenting hematoma. The other patient died 6 months after endovascular treatment due to pulmonary edema. The last patient is still recovering after emergency treatment of a ruptured flow-related PICA aneurysm. The patient who remains symptomatic showed temporary improvement after successful surgery but subsequently developed headache without evidence of hydrocephalus or recurrence on imaging (Table 4).
DISCUSSION

Classification and Venous Features
In descriptions of TDAVs, the term “incisura” is used ambiguously. For example, Ono et al.22 called it “tentorial edge” and Wollschlaeger and Wollschlaeger,21 “free margin of the tentorium.” Literally it means “opening,” which would restrict the term to the hiatus and not the adjacent tentorium or its anterior free edge.7 To avoid confusion, we have simply divided TDAVs into midline and mediolateral lesions and used conventional anatomic landmarks to separate the former.

In contrast to the more frequent DAVF of the lateral sinus located within the sinus wall2,5 and associated with sinus thrombosis,4,8 TDAVs are typically located in the dura not directly connected to major sinuses.2,5 However, among our patients, all 4 torcular TDAVs showed some degree of major sinus thrombosis. This observation may indicate that they had or have direct connections with the sinus and explain their more benign angioarchitecture, with 2 of the 4 being classified as Cognard type II a + b. It may also be a clue to their etiology, because prior sinus thrombosis is a probable cause for the development of lateral and sigmoid sinus DAVFs.8 Torcular TDAVs could thus represent an intermediate entity between sinus and purely tentorial fistulas. Two torcular TDAVs were graded as Cognard type IV, which may indicate a stage in the development of the fistula with extension into the reflected dural layers of the tentorium. In any event, all the torcular TDAVs drained both infratentorially and supratentorially, so the location appears to act as an anatomic venous epicenter connecting both supra- and infratentorial compartments.

In this series, TDAVs of the falx cerebelli were remote from a major sinus, consistently drained infratentorially, and were graded Cognard type III or IV. The extent of the falx cerebelli varies from a midline thickening of the dura to a septum extending from the inferior surface of the straight sinus to the foramen magnum. In its more complete form, it rarely extends farther anteriorly than the midpoint of the straight sinus, which is often the site of cerebellar veins connecting to the sinus (eg, declival veins). This variability could explain overlap with torcular-located lesions at 1 extreme and the solely infratentorial drainage of TDAVs when the falx cerebelli is fully formed. It also explains the frequency of hemorrhage at presentation in the latter situation. Furthermore, because TDAVs of the falx cerebelli were not associated with major sinus thrombosis, their etiology may differ from that of torcular and petrotentorial TDAVs.5,19 One possible cause is trauma, because one of our patients had had an occipital craniotomy. One can speculate that the superior attachment of the falx cerebelli could act as a stress point for traumatic vessel injury.

Our observed venous drainage routes support the classification of TDAFs proposed by Picard et al.,5 who divided TDAFs into 3 groups: 1) the tentorial marginal type with the fistulas located along the free edge of the tentorial hiatus and draining both

FIG 4. Falx cerebelli TDAVF [patient 1]. Injections of the left vertebral artery in anteroposterior [A] and lateral [B] views and superselective injection of the ADS [C] and medial dural-tentorial branch of the SCA [D]. The fistula supply arises from the left ADS [black arrow] and left medial dural-tentorial branch of the SCA [white arrow]. The asterisk marks a connection between these 2 arteries within the tentorium.

FIG 5. Falx cerebelli TDAVF [patient 2]. Injections of the left vertebral artery in lateral [A] and anteroposterior [B] views. Arterial supply to the fistula arises, among others, from the medial dural-tentorial branch of the right SCA [white arrows] and the right posterior meningeal artery [black arrows]. Additional supply from branches of the external carotid artery and the marginal tentorial artery are not shown.
supra- and infratentorially, 2) the tentorial lateral type adjacent to
the lateral sinus and draining to supratentorial veins, and 3) the
tentorial medial type with fistulas sited adjacent to the torcular
and straight sinuses draining to the infratentorial draining system.
Lawton et al\textsuperscript{7} proposed a classification with 6 anatomic locations
and venous drainage patterns. This classification was based on a
larger series of 31 patients and separates midline lesions into Ga-
lenic, straight sinus, and torcular. The last 2 have drainage pat-
terns similar to those of our falx cerebelli and torcular subtypes.

Arterial Characteristics

The tentorium derives its principal arterial blood supply from
tentorial branches of the ICA and dural branches of the vertebral
artery and external carotid artery. These arterial systems are men-
ingeal or dural and are usually identifiable on angiography in the
nonpathologic state. Additional transarachnoid supply from the
primarily pial arteries, such as the cortical branches of the PICA
and contributions to the subarachnoid plexus at the internal acoustic
meatus from the AICA,\textsuperscript{9} is less evident, unless abnormally hyper-
trophied. Whether such transarachnoid arterial traffic is “nor-
mal” or only develops in response to the development of a DAVF
is difficult to establish in vivo, and we generally rely on postmor-
tem descriptions. The identification of a tentorial branch of the
posterior cerebral artery, the ADS, was only after its enlargement
in response to pathology.\textsuperscript{21} We assume that this explains the de-
velopment of the medial dural-tentorial branch of the SCA iden-
tified in our patients. Both arteries appear to supply medially sited

Table 2: Anatomic and angiographic findings

| No. | Site         | Location         | Drainage          | Grade\textsuperscript{a} | Arterial Feeders                                                                 |
|-----|--------------|------------------|-------------------|-------------------------|----------------------------------------------------------------------------------|
| 1   | Falx cerebelli | Midline          | Infratentorially  | IV                      | Meningohypophyseal trunk, ADS, SCA                                               |
| 2\textsuperscript{b} | Falx cerebelli | Midline          | Infra- and supratentorially | IV                | Occipital, middle meningeal, posterior meningeal arteries, meningohypophyseal trunk, SCA |
| 3   | Falx cerebelli | Midline          | Infratentorially  | IV                      | Occipital, middle meningeal, posterior meningeal arteries                         |
| 4   | Torcular      | Midline          | Supra- and infratentorially | II a + b          | Occipital, middle meningeal, posterior meningeal arteries, ascending pharyngeal arteries, meningohypophyseal trunk, vertebral artery branches |
| 5   | Falx cerebelli | Midline          | Infratentorially  | IV                      | PICA, posterior meningeal artery                                                  |
| 6   | Petrotentorial right | Right         | Infratentorially  | IV                      | Middle meningeal, ascending pharyngeal arteries, meningohypophyseal trunk, AICA    |
| 7   | Torcular      | Midline          | Supra- and infratentorially | II a + b          | Occipital, middle meningeal, ADS, SCA                                             |
| 8   | Torcular      | Midline          | Infra- and supratentorially | IV                | Occipital, posterior meningeal arteries, meningohypophyseal trunk, ADS, SCA       |
| 9   | Falx cerebelli | Midline          | Infratentorially  | IV                      | Occipital middle meningeal, falcial arteries                                      |
| 10  | Falx cerebelli | Midline          | Infratentorially  | III                     | Vertebral artery branches, PICA, SCA                                             |
| 11  | Falx cerebelli | Midline          | Infratentorially  | IV                      | Occipital, middle meningeal, posterior meningeal arteries, PICA, ADS              |
| 12  | Petrotentorial left | Left            | Infra- and supratentorially | II a + b          | Occipital, middle meningeal, falcing, ascending pharyngeal arteries, meningohypophyseal trunk, inferolateral trunk, AICA |
| 13  | Torcular      | Midline          | Supra- and infratentorially | IV                | Occipital, middle meningeal, posterior meningeal arteries, meningohypophyseal trunk |

\textsuperscript{a} According to Cognard et al.\textsuperscript{20}

\textsuperscript{b} Previous surgery.

Table 3: Treatments

| No. | Method of Treatment | Embolic Material | No. of Embolized Arterial Feeders | Route | EVT Sessions | Complications |
|-----|---------------------|------------------|----------------------------------|-------|--------------|---------------|
| 1   | EVT                 | Glubran, Onyx    | 2                               | Transarterial | 1 | None          |
| 2   | EVT                 | Onyx             | 1                               | Transarterial | 1 | None          |
| 3   | EVT                 | Onyx             | 1                               | Transarterial | 1 | None          |
| 4   | EVT                 | Coils, Onyx      | 1                               | Coils, transvenous; Onyx, transarterial | 2 | Dissection   |
| 5   | EVT                 | 3 Coils          | 1                               | Transarterial | 1 | None          |
| 6   | EVT                 | Glubran, Onyx    | 2                               | Transarterial | 1 | Perforation   |
| 7   | EVT                 | Onyx             | 1                               | Transarterial | 1 | None          |
| 8   | EVT                 | Onyx             | 2                               | Transarterial | 2 | None          |
| 9   | 1) Surgery 2) EVT after recurrence | Glubran, Onyx | 6                               | Transarterial | 3 | Microcatheter rupture |
| 10  | Surgery after failed EVT | None       | N/A                             | N/A               | 1 | None          |
| 11  | EVT                 | Glubran to flow aneurysm | 1 | Transarterial | 2\textsuperscript{a} | None          |
| 12  | EVT                 | Onyx, coils      | 2                               | Both            | 3 | Microcatheter rupture |
| 13  | EVT                 | Onyx             | 1                               | Transarterial   | 1 | None          |

Note:—N/A indicates not applicable; EVT, endovascular treatment.

\textsuperscript{a} Incomplete Onyx embolization 4 years previously at another hospital; fistula then already present.

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TABLE 4: CLINICAL AND ANATOMIC OUTCOMES

| No. | Clinical Result                  | Anatomic Result                  |
|-----|----------------------------------|----------------------------------|
| 1   | Died 2 weeks later due to edema  | Cure                             |
|     | with brain stem compression      |                                  |
| 2   | Cure                             | Cure                             |
| 3   | Improved                         | Cure                             |
| 4   | Improved                         | Subtotal occlusion               |
| 5   | Died due to pulmonary edema 8   | Subtotal occlusion               |
|     | months later                      |                                  |
| 6   | Improved                         | Subtotal occlusion               |
| 7   | Cure                             | Cure                             |
| 8   | Improved                         | Subtotal occlusion               |
| 9   | Improved                         | Subtotal occlusion               |
| 10  | Unchanged                        | Cure (surgery)                   |
| 11  | Residual symptoms (treatment     | PICA aneurysm occluded           |
|     | ongoing)                         |                                  |
| 12  | Improved                         | Subtotal occlusion               |
| 13  | Cure                             | Cure                             |

CONCLUSIONS

Endovascular therapy was effective in this series, and arteriography was essential for diagnosis and planning. The medial dural-tentorial artery of SCA supplies midline TDAVs, has a characteristic course along the tentorium, and should be included in future descriptions of tentorial blood supply.

ACKNOWLEDGMENTS

We thank Alison Clarke for help in preparing the manuscript, Henry Byrne for drawing Fig 1, and our colleagues at the John Radcliffe Hospital for their support.

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