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Hybrid capability to Integrate Multiple Treatment Modalities for Managing High-Grade Intracranial Dural Arteriovenous Fistulas

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Key Words

Hybrid Capability

Dural Arteriovenous Fistulas

Multimodality Treatment

Abstract

Introduction: An integrated multimodality approach can be effective in the treatment of high-grade dural arteriovenous fistulas (DAVFs). Nevertheless, this requires a high level of efficient cooperation between different departments, underlying a degree of bias in the decisional process. In comparison, hybrid capability, integrating these modalities in one hand, may allow aggregating multimodality treatment strategies by pooling their individual benefits, essentially leading to a more holistic view of the actual consequences of each modality.

Method: We retrospectively reviewed 18 cases of DAVFs subjected to a hybrid approach, treated at the *Diakonieklinikum Jung-Stilling* in Siegen (Germany) between March 2008 and January 2017. 9 cases were excluded. We selected 4 cases for illustrative purposes, that highlight different aspects of hybrid capability.

Discussion: Hybrid capability allows treatment of a DAVFs purely based on the individual clinical situation of the patient and feature of the lesion, free of an inter-departmental bias. The surgeon maintains a level of flexibility, enabling him to move from a minimally invasive endovascular approach to a maximal invasive surgical access according to the on-line situation. In its full perfection, it can lead to a highly efficient treatment regime with palliation of symptoms and complete obliteration of the fistula, essentially powering performance in these complex pathologies.

Conclusion: Hybrid capability has great potential in the treatment of complex neurovascular lesions. It remains to be seen, if a single surgeon with hybrid capability can truly supersede the current multi-departmental practice and achieve better outcome.

Introduction

Intracranial dural arteriovenous fistulas (DAVFs) are pathological anastomoses between arterial feeders and cortical veins or venous dural sinuses ^[1]. High-grade DAVFs are defined by the presence of cortical venous drainage, most commonly classified as Borden II and III ^[2]. Patients with untreated high-grade DAVFs have an annual mortality rate of up to 10.4% ^[3] and a subsequent hemorrhage rate of up to 35% within the first two weeks after the primary incidence ^[4]. It is therefore crucial to treat high-grade DAVFs timely with modalities expected to eliminate the risk of further hemorrhage. These vascular lesions are however often composed of a complex vascular angioarchitecture, posing a particular challenge in the attempt to achieve an angiographic cure (complete obliteration of arterio-venous fistulation)^[5]. Current treatment modalities involve endovascular embolization, microsurgery and stereotactic radiosurgery, which is often reserved for cases where embolization has failed and microsurgery carries an inappropriate risk^[1]. Several series have already shown how microsurgical and endovascular treatments can be complementary in the management of these complex lesions ^[5-10]. Natarajan et al. has gone further establishing an algorithm, integrating multiple treatment modalities of DAVFs, to create a specific treatment plan in accordance to the angioarchitecture and symptomatic nature of the individual DAVF ^[5-9].

An integrated multiple modality approach however, presupposes an efficient cooperation between clinicians, microsurgeons, interventional radiologist and on occasion stereotactic radio-surgeons. In comparison, a hybrid approach, which integrates these modalities in one hand, may allow aggregating multimodality treatment strategies by pooling their individual benefits, essentially leading to a more holistic view of the actual consequences of each modality.

Since 2004 the neurosurgical department of the *Diakonieklinikum Jung-Stilling* in Siegen (Germany) has integrated microsurgery and interventional radiology within the same department in a hybrid fashion, so far having treated over 970 vascular pathologies.

We believe that a patient-based targeted combination and integration of multiple modalities within the same department, maintains a flexible treatment protocol in accordance with the clinical presentation and individual angioarchitecture at all times, and can help in achieving best possible clinical and radiological outcome.

In this study, we reviewed our experience with patients subjected to a hybrid integrated multimodality treatment approach of DAVFs, illustrating 4 cases in detail to elicit our philosophy.

Methods

After obtaining approval of the ethical committee, we retrospectively reviewed 18 cases of DAVFs treated at the *Diakoniekrankenhaus Jung-Stilling* in Siegen between March 2008 and January 2017. After excluding low-grade DAVFs and patients who received prior treatment in another institution, nine patients were left for further analysis. Pre- and postoperative clinical and radiographical data, including age, gender, presenting symptoms, pathology and its related information, and functional status as measured by the modified Rankin score (mRS) were obtained and reviewed, including all accessible follow-up information (*Table 1*). For illustrative purposes, we selected four cases that highlight different aspects of hybrid capability. Informed consent was obtained by all subjects.

Departmental Setup

Currently the neurosurgical department of the *Diakoniekrankenhaus Jung-Stilling* in Siegen has two neurosurgical consultants committed to neurovascular pathologies under the supervision of Prof. Dr. V. Braun (final author of this manuscript). One of these consultants is focused on neurovascular microsurgery, the other has hybrid capability as does V. Braun. All neurovascular cases at our institution are exclusively treated by neurosurgeons, either

microsurgically, endovascularly or combining both modalities. Cases necessitating stereotactic treatment are transferred to another institution.

Embolization Procedure and Microsurgery

All endovascular procedures were performed in a biplane angiographic unit with 3D-rotational-capability. After transfemoral cannulation, a diagnostic angiography (arterial and venous phase) was performed including the internal and external cranial arteries (ICA, VA, ECA). Embolization was exclusively performed via a trans arterial approach with the use of Onyx-20. Complex lesions with multiple feeders were treated in several consecutive sessions, with some eventually being treated microsurgically (as described in detail in the illustrative cases). The microsurgical approach depended on the location and nature of the specific DAVF. However, independent of the modality used, the primary endpoint of treatment was always palliation of symptoms and complete angiographic obliteration of the fistula.

Illustrative Cases

Case 1 (*Patient 9 in our series*)

A 61-year-old man was admitted in an external clinic due to dizziness and severe headaches after work. He also reported excessive sweating and an impairment of speech. A CT scan revealed a right-sided infratentorial hemorrhage. The patient then suffered progressive loss of vigilance and became dysarthric. He was then transferred to our clinic for further treatment. Angiographically a high grade DAVF (*Cognard Typ IV, Borden III, Zipfel IIIs*) was diagnosed, with two prominent arterial feeders. One feeder was embolized endovascularly (*Figures 1 and 2*). An attempt to eliminate the second feeder failed (*Figures 3 and 4*). The fistula was thus resected microsurgically, via an infratentorial approach in the sitting position. The final angiography showed no residual perfusion of the fistula. The patient was discharged

in a fully orientated, self-dependent state, with a slightly atactic gait. On annual follow-ups, no reperfusion has been detected so far.

Case 2 (*Patient 1 in our series*)

A 30-year-old man was admitted in an external clinic due to sudden headache and vertigo. Angiographically a high grade DAVF (*Cognard Typ IV, Borden III, Zipfel IIIs*) in the posterior fossa was diagnosed (*Figures 5 and 6*). A day later, the patient suffered a decrease in vigilance due to an acute subdural hematoma. The patient was transferred to our clinic for immediate surgical treatment. The hematoma was evacuated and an external ventricular drainage was placed. After initial improvement and stabilization, elective endovascular treatment of four arterial feeders was performed in a total of four sessions. At final discharge the patient presented in a fully orientated, self-dependent state with a slight left-sided hemiataxia. The final angiography showed no residual perfusion. After five years, the patient was readmitted due to new onset of vertigo. The angiography revealed a reperfusion of the fistula via two new feeding branches (*Figures 7 and 8*). One feeder was closed endovascularly. An attempt to close the second feeder failed, so the patient was referred to stereotactic radiosurgery, as he declined microsurgical treatment.

Case 3 (*Patient 7 in our series*)

A 70-year-old woman was involved in a minor road traffic accident. Due to confusion, headache and possible initial loss of consciousness prior to the accident, a CT-scan was performed in an external hospital, revealing a right sided occipital intracranial hemorrhage. The patient was transferred to our clinic for further investigation and treatment. Angiographically a high grade DAVF (*Cognard Typ IV, Borden III, Zipfel IIIs*) in the posterior fossa, with feeders from the right middle meningeal artery (MMA) (*Figure 9*) and the right occipital artery (OA) was diagnosed. Endovascular treatment of the MMA was

performed in one session, showing significant residual perfusion via multiple branches from the OA (*figure 10*). An endovascular approach was not feasible, so the indication for microsurgical resection was made. Prior to the surgery, another angiography however revealed a decline in perfusion (*figure 11*). It was thus decided to await possible spontaneous closure. 3-month, 6-month and 1-year follow-ups showed a further decline in residual perfusion with no signs of upward conversion to a high-grade DAVF (*figure 12*). Therefore, further treatment did not seem justified. Apart from slight visual impairment, the patient suffered no neurological deficits.

Case 4 (Patient 6 in our series)

A 55-year-old man was admitted to our department due to syncopal episodes of unknown origin and therapy resistant epileptic seizures. An initial MRI showed a DAVF in the anterior cranial fossa. For definite diagnosis, an angiography was performed. This showed a high grade DAVF (*Cognard Typ IV, Borden III, Zipfel IIIs*) with feeders from both OpAs, the right MA (via ethmoidal branches) and both MMAs (*Figures 13-15*). Due to the ophthalmic involvement, an endovascular approach did not seem reasonable. The DAVF was therefore successfully resected microsurgically with a supraorbital approach. A postoperative angiography (*Figure 16*), performed immediately after the operation, confirmed the total elimination of the fistula. The patient was discharged with no neurological deficits. On three consecutive annual follow-ups, no reperfusion of the fistula was detected on the TOF-MRI. Moreover, the patient remained free of seizures.

Discussion

The management of intracranial DAVFs has been a controversial topic of debate in recent years regarding the optimal approach^[1, 4]. High-grade DAVFs are often composed of a

complex angioarchitecture, posing a particular challenge in the attempt to achieve symptomatic and angiographic cure. While endovascular treatment achieves palliation of DAVF-related symptoms at a low peri-procedural complication rate, it often comes at a cost of incomplete obliteration of the fistula.^[10-13] Microsurgery on the other hand achieves far higher obliteration rates between 96-100%^[14-16], but carries a surgical morbidity and mortality rate between 4 to 17%^[10, 14, 16-18]. With reported obliteration rates as low as 68%^[19] and an exceptionally high time to treat (average of 2 years), radio-surgery is only appropriate for DAVFs without CVD, thus low-grade DAVFs^[1].

Several series have shown how high-grade DAVFs with complex angioarchitecture are most effectively managed via a combination of endovascular, microsurgical and/or radio-surgical therapy^[20]. However, therapeutic decisions that are made in a collaborative fashion by neurosurgeons, interventional radiologists and radio-surgeons may be subjective to a high degree of bias depending on the interest of the centre and possibly even on a dominant arm within the multi-disciplinary team. What is more, at least in the German insurance and reimbursement setting, monetary aspects may also have an inadequately objectifiable influence within a multimodality decision process.

Even though an endovascular approach is widely accepted as the first-line treatment of DAVFs, Youssef et al. for instance^[21], argues that the advances in microsurgical and skull base approaches have allowed surgeons to approach and obliterate fistulas with little or no retraction of the brain, limiting post-operative complication rates. In some centres, this has led to a renaissance of microsurgery in the treatment of complex cases of DAVFs, which may have been initially considered to be favorable for endovascular- or radiotherapy^[21-24].

Departments that depend heavily on an endovascular team, have likewise benefited from the advances in endovascular agents since the introduction of Onyx, extending the treatment indications for DAVFs^[25-27]. Even stereotactic radiotherapy is extensively used in different institutes to treat high-grade DAVFs conjunctively with endovascular treatment or as a sole

treatment modality^[28-30]. Our normal bias in choosing the modality of treatment is included in our subspecialties. Undoubtedly, the decision of treatment is to a certain degree based on the doctors training program.

We hypothesize that state-of-the-art treatment of complex neurovascular pathologies is not by definition multi-disciplinary. It does however demand multiple approaches to a specific lesion to guarantee best possible outcome. Historic developments (and not to underestimate regional-specific settings), have lead to various approaches not necessarily being accredited to the same medical discipline. Consequently, in the face of the impressive evolution of minimally invasive neuro-endovascular treatment, which most commonly is performed by neuro-radiologists (at least in the European setting), inevitably mandates a multi-disciplinary setup in institutions dedicated to the treatment of neurovascular pathologies. If however, one discipline unifies two mutually complementary approaches within one department, which is essentially the definition of hybrid capability, state-of-the-art treatment of neurovascular pathologies would no longer necessitate multi-disciplinary cooperation.

Hybrid capability of all modalities, allows the neurosurgeon to manage a DAVF purely based on the individual clinical situation of the patient and feature of the lesion. The surgeon maintains a level of flexibility, enabling him to move from a minimally invasive endovascular approach to a maximal invasive surgical access according to the on-line situation. Hybrid approaches allow aggregating all available modalities to make use of their individual benefits and leading to a more holistic view of the actual consequences that come with each modality. In its full perfection, it can lead to a highly efficient treatment regime with palliation of symptoms and complete obliteration of the fistula, essentially powering performance in these complex pathologies.

The illustrative cases each portray a different aspect of the hybrid capability practiced in our institution. Case 1 is an example of how endovascular treatment can be complementary to microsurgical resection. The involvement of a tortuous marginal tentorial artery impeded a complete endovascular obliteration of the fistula considerably. Microsurgery was the only option for this patient to achieve complete obliteration of the DAVF. Nevertheless, the endovascular approach was used to obliterate the main arterial feeder causing a significant flow reduction and facilitating the latter operative resection.

Case 2 illustrates the high degree of flexibility derived from hybrid capability. While the patient was initially cured endovascularly, he suffered a re-canalization of the fistula on a five-year follow-up after a new onset of symptoms. As another endovascular attempt failed, we offered microsurgery, which the patient declined. As a final resort, stereotactic radiosurgery was offered. On Follow-ups after gamma knife treatment, only minimal residual perfusion was noted.

Case 3 was chosen to emphasize the “*wait and see*” strategy. Initially, microsurgery was scheduled for this patient due to significant residual perfusion after endovascular embolization. In the final angiography prior to the operation the perfusion seemed to be declining. As we had no inter-departmental pressure to treat the patient immediately, a “*wait and see*” strategy was pursued. On the follow-ups, the residual feeders proved barely visible.

Finally, case 4 portrays a clear surgical case, due to the ophthalmic involvement of the fistula. Nevertheless, hybrid capability also has its justification here. To confirm complete obliteration, an angiography was performed immediately after the microsurgical resection, maintaining the option of revising a potential residual fistulation surgically within the same session of anesthesia. As of 2017 this has been significantly facilitated by the introduction of two Hybrid-Operating Rooms in our institution, allowing angiographic real-time information during the operation, without the need for patient transportation.

A Hybrid approach by its natural ability improves the decision process and shows great potential for becoming most relevant in future decision making. One modality, for example, could provide the predicting scale for a challenging situation, whereas a second modality could be integrated to work as a decision support tool. The hybrid surgeon revolves in a spectrum of minimal invasive to maximal invasive according to the case-by case situation, tapering his procedure on line. Hybrid capability is favorable in the face of complex vascular pathologies as it allows the neurosurgeon to gain an internal and external perspective of the vascular lesion at the same time, consequently leading to an even more profound understanding of the vascular pathology and essentially most suitable treatment option.^[31] The decision is not based on the question of who is best to treat the patient, but much rather what is the best treatment for the patient.

For some reason, hybrid capability has been neglected in the field of neurosurgery. In comparison, other medical fields such as cardiothoracic surgery and vascular surgery, have integrated angiographic ability and surgical prowess in a hybrid fashion for many years^[32, 33].

Many steps could be done to support the concept of a hybrid neurosurgeon, such as initiating a focused training program for residents encouraging a subspecialisation at an early stage of their career. Moreover, the introduction of hybrid operating rooms supports the hybrid idea and has already been implemented in many institutions (ours included). *Liao et al* just recently published their 5-year experience with a hybrid operating room in the treatment of cerebrovascular diseases, classifying DAVFs as lesions with a high level of necessity (*Level A*) in regard to the use of a Hybrid-OR.^[34]

Will the advances in technology yield a new generation of singular hybrid interventionalists?

It remains to be seen, if a single surgeon with hybrid capability integrating numerous modalities can truly supersede multi-departmental practice and achieve better outcome.

Conclusion

It looks as though there is a new trend emerging in the neurovascular field, embodying a new generation of neurosurgeons with hybrid capability to complement endovascular with microsurgical treatment. Hybrid capability potentially eliminates the setbacks of multi-disciplinary practice, whilst maintaining state-of-art treatment by implementing mutually complementary approaches to complex neurovascular lesions within one surgeon. However, multi-center studies will be necessary to determine, whether one surgeon with fully trained integrated multitasks is better for the patient's interest than multiple individuals with diverse opinions and treatment approaches.

Limitations

The key limitation of this study is its retrospective nature and relatively low case number in respect to the considered time frame. This is single center study. Consequently, the main treating physician also reviewed the outcomes and is a co-author in this publication. Hybrid capability in our center includes endovascular and microsurgical treatment, but does not entail radio-surgical intervention. For radio-surgical treatment, patients were referred to another clinic.

Disclosures

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Figure Captions

Figure 1 –arterial phase of the right vertebral artery (VA): opacification of the dural av fistula via the right posterior meningeal artery (PMA)

Figure 2 – arterial phase of the right VA after embolization of the PMA (arrow): no opacification of the fistula

Figure 3 – arterial phase of right internal carotid artery: opacification of the dural av fistula via the marginal tentorial artery (a.k.a. artery of bernasconi & cassinari) (BerA)

Figure 4 – attempt to embolize the BerA: not possible due to tortuous course of the artery

Figure 5 – late arterial phase of left VA: opacification of the DAVF via the posterior meningeal artery (PMA), the anterior inferior cerebellar artery (AICA) and the superior cerebellar artery (SCA)

Figure 6 – early arterial phase of left external carotid artery (ECA): opacification of the dural av fistula via the ascending pharyngeal artery (APA)

Figure 7 – arterial phase of left ECA: reperfusion of the DAVF via the ascending pharyngeal artery (APA)

Figure 8 – arterial phase of left ICA: reperfusion of the DAVF via the marginal tentorial artery a.k.a. artery of bernasconi & cassinari (BerA)

Figure 9 – arterial phase of right ECA: opacification of the DAVF via the right middle meningeal artery (MMA)

Figure 10 – after embolization of MMA, residual perfusion out of branches from occipital artery (OA)

Figure 11 – declining residual perfusion out of branches from right OA (arrow)

Figure 12 – 1 year follow-up: perfusion of the fistula via OA barely visible (arrow)

Figure 13 - late arterial phase: early filling of the superior sagittal sinus (SSS), the right ophthalmic artery (OpA) feeds the cortical vein and a venous aneurysm (VenA)

Figure 14 – early arterial phase of the right ECA: the right maxillary artery (MA) and the right middle meningeal artery (MMA) feed the fistula

Figure 15 – late arterial phase of left ECA: the left meningeal media artery (MMA) feed the fistula

Figure 16 – postoperative angiography – no residual perfusion of the fistula

Table 1. Summary of Patient Demographics, Treatment Modality, Complications and Outcome Data

No.	Age (years)	Sex	Location	Borden Type	Cognard Type	Zipfel Type	Hemorrhage on Presentation	Treatment Modality	Complication	Follow-up (months)	Radiological outcome	Clinical outcome (mRS)	Comment
1	30	M	IT	III	IV	III _s	IPH	EV + GK	None	3, 14, 21, 59	RP (at 59)	1	Patient referred to stereotactic radiosurgery
2	81	M	TS	II	IIa + b	IIa	No	EV	None	LTF	LTF	0	Patient was diagnosed with Bronchial Cancer – follow ups were not realized
3	71	F	IT	III	IV	III _s	IVH	EV	VP-Shunt	LTF	LTF	5	
4	53	M	ACF	III	III	IIIa	No	MS	CSF leakage	3, 15, 21, 27, 37	CO	1	Revision surgery was necessary to treat the CSF leakage
5	66	M	ACF	III	IV	III _s	No	MS	None	6	CO	0	Patient died due to Glioblastoma 42 months after DAVF Treatment
6	54	M	ACF	III	IV	III _s	No	MS	None	3, 17, 41	CO	0	
7	70	F	IT	III	IV	III _s	IPH	EV	None	3,7	RP	1	
8	53	M	ACF	III	IV	III _s	IPH + IVH	MS	None	LTF	CO	3	No residual perfusion at discharge, patient did not turn up on scheduled follow-ups
9	61	M	IT	III _b	IV	III _s	IPH	EV+MS	None	7	CO	1	

IT = infra-tentorial; TS = transverse sinus; ACF = anterior cranial fossa; IPH = intra-parenchymal hemorrhage; IVH = intra-ventricular hemorrhage; EV = endovascular; MS = microsurgical; GK = gamma knife; VP = ventricular-peritoneal; CSF = cerebrospinal fluid; LTF = loss to follow-up; RP = residual perfusion; CO = complete obliteration; mRS = modified ranking scale

ACCEPTED

Abbreviations List

ACF – Anterior Cranial Fossa

AICA – Anterior Inferior Cerebellar Artery

APA – Ascending Pharyngeal Artery

BerA - Artery of Bernasconi & Cassinari

CO – Complete Obliteration

CVD – Cortical Venous Drainage

DAVF – Dural Arteriovenous Fistulas

ECA – External Carotid Artery

EV – Endovascular

GK – Gamma Knife

ICA – Internal Carotid Artery

IPH – Intra Parenchymal Hemorrhage

IT – Infra Tentorial

IVH – Intra Ventricular Hemorrhage

MA – Maxillary Artery

MMA – Middle Meningeal Artery

mRS – Modified Ranking Score

MS – Microsurgical

OA – Occipital Artery

OpA – Ophthalmic Artery

PMA – Posterior Meningeal Artery

RP – Residual Perfusion

SCA – Superior Cerebellar Artery

SSS – Superior Sagittal Sinus

TS – Transverse Sinus

VA – Vertebral Artery

VenA – Venous Aneurysm