

DECLARATION

I hereby declare that the thesis entitled **“ONYX EMBOLISATION OF ADULT TYPE DAVF: ANGIOGRAPHIC PREDICTORS OF COMPLETE OCCLUSION & CLINICAL CORRELATION OF ANGIOGRAPHIC RESULTS”** is an independent work carried out by me, under the supervision and guidance of Dr. Jayadevan E.R., (Associate Professor), and Dr. Kapilamoorthy T. R., (Professor & Head), Department of Imaging Sciences and Interventional Radiology, Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram and it has not been submitted anywhere else for any other degree, diploma or title.

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CERTIFICATE

This is to certify that the work embodied in the thesis entitled “**ONYX EMBOLISATION OF ADULT TYPE DAVF: ANGIOGRAPHIC PREDICTORS OF COMPLETE OCCLUSION & CLINICAL CORRELATION OF ANGIOGRAPHIC RESULTS**” for degree of DM (NEUROIMAGING AND INTERVENTIONAL NEURORADIOLOGY) has been carried out by Dr. Anand M., under my supervision and guidance. The work done in connection with this thesis was carried out by the candidate himself and is genuine.

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**ONYX EMBOLISATION OF ADULT TYPE DAVF:
ANGIOGRAPHIC PREDICTORS OF COMPLETE OCCLUSION &
CLINICAL CORRELATION OF ANGIOGRAPHIC RESULTS**



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INTRODUCTION

Intracranial Dural arterio venous malformations (DAVF's) are thought to represent 10-15 % of all intracranial vascular shunting malformations(1). They are abnormal arterio venous shunts between dural branches of External carotid arteries and dural veins/ osteo dural veins. Pial supplies to these lesions are rare. Clinically they may be asymptomatic or present with headaches, tinnitus, visual complaints, non hemorrhagic neurologic deficits, seizures and intracranial hemorrhage (2). The clinical presentation, course, and complications depend on topography of the lesion and more importantly, presence and absence of reflux venous drainage termed as cortical venous reflux (CVR)(3).

For clarification of terminology DAVF in the ensuing discussion are distinguished from the other arterio venous shunts involving the dura like, Post traumatic dural fistulae like Carotid cavernous fistulae, Dural fistulae resulting from rupture of pre existing arterial aneurysms and dissections into adjacent venous structures like in various primarily dysplastic arteriopathies and other causes of transdural supply to a pial arterio venous lesions and proliferative angiopathy(4).

Initially thought to be congenital, it is now known that this entity comprises of etiologically and morphologically heterogeneous group of vascular malformations including dural sinus malformations (DSMs), infantile dural arterio venous fistulae and adult type dural arterio venous fistulae(5). Only the DSM are clearly congenital lesions. The adult type DAVF have an incidence of 0.16 per 100,000 adults per year (1). This may however be an under estimation as a good number of lesions may be asymptomatic and hence not reported. The most

common predisposing factor for development of dural fistula appears to dural sinus thrombosis and multiple predisposing factors contributing to thereof (5, 6).

The description of the dural fistulae was given in a publication by **Fischer** et al (7). The initial classification scheme was proposed by **Djindjian & Merland** based on venous drainage pattern and presence and absence of cortical venous reflux (8). Further pivotal studies regarding this disease by **Malik et al** (9) and **Lasjaunias** et al (10) have reinforced this fact. **Awad** et al (5) had noticed that in addition to CVR, presence of venous ectasia and deep venous drainage were also poor prognostic features. Current Neuro vascular literature regarding DAVF reporting and management is dominated by the **Borden's** classification or the **Cognard's** classification (3), which in turn are also centered on the presence or absence of cortical venous reflux for ascribing severity grades to these lesions.

Management of the lesions may be conservative or aggressive depending on the clinical presentation, angiographic characteristics and severity grading also keeping in perspective the patient related factors including, but not limited to comorbid conditions. Aggressive management strategies consist of achieving a disconnection of abnormal arterio venous shunting zone and may be achieved by Micro neuro surgical techniques, endovascular management or by stereotactic radiosurgical methods. Each modality has its own advantages and disadvantages depending on given the situation at hand. Complete cure may at times warrant the administration of two or all three of these sequentially or simultaneously.

Endovascular treatment of DAVF consisted of transarterial particulate embolics in the beginning. Later advances in catheter and embolic material technology revolutionized neuro endo vascular management of intra cranial

vascular malformations and Endo vascular management of DAVF has followed suit with development of transvenous techniques of particulate and liquid embolics and more recently since the inception of “Onyx ; ev3, Irvine, California” (Ethylene Vinyl alcohol copolymer with DMSO as solvent and micro ionized tantalum powder for radioopacity) the treatment has come a full circle by again shifting the focus on to trans arterial endovascular management in most of the lesions, with the more risky transvenous approach being relegated to niche applications only (11). Onyx due to its unique properties made it feasible to undertake the complete cure of this lesion in a single sitting itself for most if not all such lesions. Advances in endo vascular armamentarium continues to evolve in the form of DMSO compatible micro catheters, balloon catheters , tip detaching catheters, floppy fully flow guided micro catheters and steerable micro wires, varying strength EVOH preparations. Transarterial endo vascular management of DAVF show parallel evolution in the form of elegant and efficient treatment strategies like Balloon protection of venous sinuses with concurrent transarterial Onyx embolization, Balloon catheter wedged tranarterial onyx injection , “the pressure cooker technique” of Onyx injection”and the like.

SCTIMST, Thiruvananthapuram is tertiary referral facility with requisite expertise and infrastructure in micro neuro surgery and neuro endo vascular interventions for management of a variety of diverse intracranial vascular malformations. The facilities include 24/7 biplane neuro interventional suite functionality, Outpatient services and inpatient facilities including 12 bedded high dependency intensive care, step down and regular ward beds. These are staffed by trained neurointerventional faculty and resident doctors in training who in turn

are ably supported by cathlab and Neuro interventional ICU Nursing staff, angiography technicians and trainees and other auxiliaries. The interventional service is well supported by the imaging wing which offers high end imaging capability with 3 & 1.5 T MRI, 256 MDCT, USG and digital and computerized radiography systems.

The department of Imaging sciences and Interventional radiology works in close coordination with the Neurology and Neuro surgical sciences and enjoys their undivided support in all its endeavors.

At SCTIMST referrals from all parts of India and abroad are entertained and over the years have accumulated a large database concerning rarest of intracranial vascular malformations including Adult type DAVFs. During this period the said lesions were treated conservatively as well as proactively by endovascular, microneuro surgical and stereotactic radiosurgical methods alone or in varying combinations of same according to management protocols prevailing in the institute at time of treatment. In this study the Neuro endovascular experience in trans arterial Onyx treatment of Adult type DAVFs of 5 years from 2010 - 2015 is presented. (At the time of the study this procedure was the national and international standard of care for bulk of the lesions warranting proactive treatment).

AIMS AND OBJECTIVES

1. To review, prospectively and retrospectively trans arterial onyx embolization for adult types of DAVFs that were treated at Department of IS&IR, SCTIMST, over a period of 5 years.
2. To analyze angioarchitecture of various types of DAVFs and ascertain if any of these are predictive of achieving complete embolization by transarterial Onyx injection and to what extent.
3. To study the procedural details in detail in these cases.
4. To study the details of the pre and post procedure and management of these cases.
5. To enumerate technical difficulties and complications encountered and suggest remedial measures/pre-emptive tactics to avoid as such in future.
6. To propose an optimized diagnostic and management strategy based on current experience
7. To evaluate the efficacy of treatment in terms of clinical and radiographic outcome when compared to the pre intervention status.

REVIEW OF LITERATURE

3.1 Early Historical perspective:

The earliest descriptions of dural arteriovenous shunts were given by **Tonnis (12)** as early as 1936. It was however **Fisher (13)** that conceptualized “spontaneous dural fistulae” in 1951. The earlier work in this direction focused almost exclusively on topographic location of the lesion (**Hayes** in 1963 (14) and **Pecker (15)** et al in 1965). Routine use of External cerebral artery injections were used to interrogate intracranial lesions was pioneered by **Hans Newton (16)** **Newton and Cronquist** 1969 (16), **Newton et al 1968 (17)**. Elaborating further on these superselective angiographic injections, **Djindjian and Merland (18)** put forth the first angio architectural classification of dural arterio venous shunts.

Table: 1 Classification of dural arterio venous shunts by Djindjian and Merland, 1978

Type I	Drainage into a sinus
Type II	Sinus drainage with reflux into cortical veins
Type III	Drainage solely into cortical veins
Type IV	With supra or infratentorial lake

The concept of Dural vascular malformations were further well entrenched by contributions from **Houser** in 1972 (19), **Aminoff** in 1973 (20), **Obrador** et al (21) in 1975 and **Choudhary** et al in 1982 (22).

Current understanding of DAVF is based on three large series. **Malik** in 1984, on the basis of a series of 223 cases, concluded that venous outflow was a key factor in the occurrence of hemorrhage or neurological symptoms (9). **Lasjaunias** analyzed 195 cases, concluding that focal neurological deficits were dependent on the territory of draining veins and that CVR was related to a high risk of intradural bleeding (10). **Awad** in his study of 377 cases introduced, the term “for DAVFs presenting with a hemorrhage or a focal neurological deficit. Awad pointed out venous ectasias and galenic drainage as additional risk factors (5).

3.2 Etiology & Pathophysiology:

Adult type DAVF are considered as acquired lesions according to current level of evidence. This fact was acknowledged as early as the 1960s, when **Castaigne and Djindjian** put forward the alternate hypothesis of an acquired etiology challenging the hitherto held notion of congenital etiology (23). According to their suggestions DAVFs are constituted by the opening up of existing micro shunts within the dura in response to ischemia with lesion proliferating in time recruiting still new collaterals by way of angiogenesis.

A multitude of factors have been proposed that lead to the initiation of these disease processes including but not limited to traumatization, iatrogenic and otherwise, tumors blocking the venous drainage, factors affecting the viscosity and rheological properties of blood including dehydration, acquired and genetic coagulopathies and infective inflammatory conditions like middle ear infections and sinonasal inflammation. The female sex is particularly vulnerable to the development of the lesion d/t a host of reasons relating to pregnancy, childbirth, puerperium, oral contraceptive pill use and menopause (24). In addition **Berenstein et al** have noted premenstrual worsening of

symptoms in females with DAVF (25). They also noted increased incidence of Sphenoid osteodural and cavernous CCF in female patients. They have hypothesized that there may be definitive hormonal target in such cases and even advised a trial of estrogen in this subset of patients. The final common event in any case appears to be cortical and dural venous sinus thrombosis with resultant venous congestion abating the normal arterio capillary venous perfusion gradient. Net result of all such events is ischemia which in and of itself is considered the most potent of all drivers of angiogenesis. This is effected by elaboration of growth factors such as Vascular Endothelial Growth Factor (VEGF) and basic Fibroblast Growth Factor (bFGF), which promotes neovascularization (26). Such angiogenesis is represented by further opening of micro shunts in the osteo dural complex thus setting in motion a self-perpetuating vicious cycle of events culminating in devastating clinical consequences when the biologic compensation mechanisms are eventually overwhelmed.

. Histopathological analysis of excised DAVFs has revealed thrombosis and angiographic progression of sinus thrombosis to dural arterio venous fistulae. It is however noted that all case of venous thrombosis do not develop DAVFs and also all dural fistulous lesions may not be invariably associated with thrombosis. These facts lend credence to the hypothesis that dural/ venous sinus thrombosis all by itself is not a fore runner of the DAVF but produces and arranges a set of loco regional hemorheologic milieu that renders a given area of dural lining more susceptible than other areas for the development of vascular shunt. So formation of Dural fistulae will require the simultaneous or sequential series of multiple events including but not limited to an inciting trigger causing venous sinus occlusion leading to ischemia and elaboration of angiogenic factors, neo vascularity and shunting response depending on the topographic location of the lesion, High flow angiopathic changes in downstream venous vasculature with resultant changes in surface

properties of veins. Further clinical expressivity of the lesion depends on topography, presence of alternative venous outlets, and development of sinus septations, compensatory reserve and adaptive response of the host.

The incidence of DAVF at various locations as reported in literature is as follows: transverse sinus 50%, cavernous sinus 16%, tentorium cerebelli 12%, and superior sagittal sinus, 8% (24).

3.3 Clinical presentation:

Clinical features including presenting complaints are quite diverse in dural fistula and may vary from a totally asymptomatic incidental pick up on imaging of head for an unrelated issue like following trauma to a disabling rapidly progressive cognitive decline or neurologic deficits or even a fatal intracranial haemorrhage. On the whole the clinical presentation depends largely on lesion location, primary and alternative collateral venous outlet available for the decompression of the shunt, flow characteristics of the shunt and severity of the reflux. Lesion location influences symptomatology to a great extent because brain damage or venous congestion/ ischemia occur in those areas that are drained by the involved dural sinus or veins that are congested. It therefore may affect eloquent or non eloquent areas of the brain; accordingly the patient may become symptomatic immediately if involved brain is eloquent and later on only if non eloquent areas are involved, as consequence of venous hypertension and global perfusion abnormalities or due to an ischemic or hemorrhagic stroke. Topographic location also decides the extent of alternative venous drainage outlets available if primary venous drainage channels are compromised or engaged by the shunt flow.

Focal neurologic deficits in patients with DAVF like cranial nerve palsies may be attributed variously to arterial steal phenomenon [Lasjaunias et al (10, 27)] as many

cranial nerves receive arterial supply from meningeal vessels exclusively and if these are involved in DAVF, there may be ischemia to cisternal components of these cranial nerves. This explanation may be the possible explanation of reversibility of cranial nerve dysfunction following successful shunt exclusion in many cases. On the other hand cranial nerve dysfunction may as well be a purely physical, as in the case of cranial nerve segments in the cavernous sinus in presence of carotid cavernous fistula where in the nerve segments get compressed by the enlarging compartments of cavernous sinus receiving the shunt flow.

Venous hypertension results in chronic CSF drainage impairment leading to features of raised intracranial pressure with papilledema and hydrocephalus. These changes may lead to global neurological deficits with symptoms of venous hypertensive encephalopathy. **Berenstein** et al (25) has noted increased incidence of such global neurological deficits in patients with transverse sinus or torcula region DAVFs.

Hemorrhages may result from rupture of fistulous communication on the venous side, or a rupture of venous ectatic pouches or a congestive venous infarct with hemorrhagic transformation. Such presentations are typically unique to shunt with retrograde venous reflux. (**Awad** et al. (28) ; **Cognard** et al. (3) have noted that certain locations of DAVF like anterior cranial fossa floor and tentorial location is associated with hemorrhagic presentation in as many as 75 to 95 % of such patients). Transient ischemic attacks may be another manifestation of steal phenomenon. More permanent and progressive focal neurologic deficits are due to congestive venous edema or pressure effects from enlarging venous channels. pressure from the enlarged arterialized cavernous sinuses resulting from cavernous region Cavernous sinus DAVF usually present with Orbital symptoms like blurring of vision, retroorbital pain, orbital and conjunctival congestion, lacrimation, papilloedema and in late stages as secondary

glaucoma and optic atrophy with vision loss. On the other hand lesion in the vicinity of Sigmoid sinus and jugular veins present with pulse synchronous tinnitus. This is because of the unusual turbulent arterialized flow in the dural venous or venous structure that are close to or in direct physical proximity with the bony housing of the hearing apparatus. Severity of tinnitus may be related to shunt severity. Dural fistulae in the region of foramen magnum or petrosal sinuses may present with symptoms of myelopathy due to perimedullary venous reflux. Dural fistula of anterior cranial fossa are more likely to present with hemorrhage and middle cranial fossa have a higher chance of cortical and orbital venous reflux.

Geibprasert et al in 2008, based on their analysis of 300 patients with DAVFs classified the lesions based on evolutionary embryology of brain, vertebral and skull base venous drainage into dorsal , ventral and lateral epidural shunts each with its own specific demographic, clinical , angiographic and therefore treatment specifications (29). According to their study the dorsal epidural fistula are present at a lower mean age with no sex predilection and is associated with multiplicity of shunts, however is not associated with presence of cortical venous reflux unless there are other venous flow constraints placed in its drainage. They also observed that ventral epidural shunts are also not associated with CVR unless there is constraint placed on its venous drainage. On the other hand in their series, the lateral epidural shunts were associated with male sex and later age of presentation and associated with CVR and aggressive natural history in 100% of cases.

3.4 Classification:

Following Djindjian's, classification numerous other schemes for cranial DAVFs have been proposed, of which the **Borden** and the **Cognard** classifications are among the

most practical most frequently applied (3, 30). In the **Borden-Shucart** system, DAVF are classified only on the basis of the site of venous drainage and the presence or absence of CVR. Further sub classification based on angiographic complexity into a single fistula or multiple fistulas (Subtypes a & b respectively) is also proposed. In the more elaborate Cognard system, additional features like dural sinus flow and venous outflow architecture are considered alongside presence or absence of CVR.

Table: 2 Borden's classification of cranial DAVF's

BORDEN TYPE	ANGIOGRAPHIC ASPECT
<i>TYPE I</i>	Venous drainage directly into dural sinus or intradural venous segment
<i>TYPE II</i>	Venous drainage into dural sinuses with CVR
<i>TYPE III</i>	Venous drainage directly to cortical vein

Zipfel et al in 2009 proposed modifiers to the Borden and Cognard classification system to include asymptomatic and symptomatic presentations associated with aggressive DAVFs (31) in order to make more efficient and treatment stratification. . He opined that DAVFs with CVR should ideally be sub stratified into those that presented initially with a hemorrhagic or non hemorrhagic neurologic deficit and those that were relatively asymptomatic or minimally symptomatic at the time of diagnosis despite the presence of CVR. Thus lesions with no CVR 1 with a low risk for ICH (< 1% risk per year) would receive conservative treatment. Lesions with CVR but asymptomatic /minimally symptomatic that carried intermediate risk for ICH (1.4–1.5% risk per year) would be triaged for a definitive management by micro neuro surgery/embolization or even by stereotactic radiosurgery. Lesions with CVR and presenting with ICH / NHND carrying a

high risk for ICH (7.4–7.6% risk per year) should be recommended for definitive management on emergent basis by surgical or endovascular means at the earliest.

Table: 3 Cognard's classification of cranial DAVF's

COGNARD TYPE	ANGIOGRAPHIC ASPECT
<i>TYPE 1</i>	Dural venous drainage with antegrade flow
<i>TYPE 2 A</i>	Dural venous drainage with retrograde flow, no CVR
<i>TYPE 2 B</i>	Dural venous drainage with antegrade flow but with CVR
<i>TYPE 2 A + B</i>	Dural venous drainage with retrograde flow with CVR
<i>TYPE 3</i>	Drainage to subcortical vein (direct CVR)
<i>TYPE 4</i>	Type 3 drainage with focal ectasia of involved veins
<i>TYPE 5</i>	Drainage to spinal perimedullary veins

The classical held view of DAVF shunt location in the wall of the dural sinus has been regarded as an oversimplification which does not allow the inclusion of a large number of real world shunts. **Piske** et al in 1988 reported the existence of so called extrasinusal lesion based on 6 year experience from 1980 -86 at the Hospital of Bicetre and opined that dural shunts may arise in any situation wherein a vein traverses bone like orbit, calvarium or skull base (32).

Morets classification into sino dural , osteodural , dural arachnoid , dural pial DAVFs and also according to location as superficial , deep, cavernous, anterior cranial fossa in addition to congenital giant torcular DAVF (possibly the dural sinus malformation).

Presence of cortical venous reflux alone is many a time not able to adequately triage patients for emergent, urgent or elective treatment. As proposed by **Baltsavias** et al in 2015, the sinusal and extrasinusal shunts with cortical venous reflux may be subdivided into 8 subtypes based on the directness, exclusivity and strain or “DES’ concept (33). Here “directness” of the shunt implies drainage occurring directly on to a bridging vein and non direct shunt implies shunt flow occurring indirectly into cortical vein via a dural sinus. The exclusivity of shunt shows whether the shunt is directed exclusively into the cortical venous system. In the non exclusive shunt, the dural venous system partakes in carrying the shunt flow to a varying extent thereby releasing the strain on the cortical venous system somewhat. The presence of “strain” indicates presence of congestive or ecstatic changes in the cortical veins receiving the shunt flow and indicates an advanced and decompensated stage of the shunt. Each of these three variables may have a binary outcome in each case and thus altogether there are eight possible combinations of shunt scenarios. The clinical presentation becomes more severe and natural history more ominous with directness, exclusivity and strain attributes of each lesion.

3.5 Natural history:

Initial meaningful insights into the natural history of DAVFs were gained from retrospective case series descriptions by **Fernand** et al 1987 (34), **Awad** et al 1990 (5) and **Cognard** et al 1995 (3). **Awad** et al in his meta analysis of 377 cases noted a significant association between presence of ICH or NHND with angiography showing cortical venous reflux, galenic drainage and presence of venous aneurysms.

The first prospective natural history study of spontaneous Adult type DAVF comes from the first large cohort of 102 patients from the University of Toronto brain vascular malformation study group by **Davies** et al in 1997 (35, 36). This seminal study had an

average follow up of 33 months for as many as 91% of patients. In this study the author noted that aggressive clinical presentation (Intracranial hemorrhage and non hemorrhagic focal deficit) were strongly associated with a tentorial as well as anterior cranial fossa location topography wise. He also attributed this to the presence of more severe grade shunting lesions being seen in these areas. There was statistically significant associations between aggressive clinical course and shunt severity Grades attributed by Borden and Cognard. Only 2% of type I Borden and 0% Cognard type I presented with an aggressive outcome, whereas 79% of type III Borden, 83% of type III Cognard and 100% of type IV Cognard lesions showed aggressive clinical course. **Brown** et al reported an annual risk of ICH of 1.8 % in 52 patients that initially presented with minor symptoms like headache, tinnitus and ophthalmologic complaints (37) . On the other hand **Duffau** et al in their series of 20 type 2 and 3 patients that presented with ICH noted a risk of 35% subsequent hemorrhage in a 20 day mean interval period (38). **Van Dijk** et al in their longitudinal follow up of 20 patients with untreated or partially treated DAVF with 5 ICH and 11 NHNDs reported a subsequent ICH rate of and NHND rate of 8.1% and 6.9%(39).

It is now well known that DAVF is a dynamic pathology. These lesions may spontaneously resolve or progress to a more severe reflux grade. In a long term follow up study of 112 patients managed conservatively by **Kim** et al published in 2010, the authors noticed spontaneous occlusion rate of 12.5% chiefly the transverse and cavernous sinus regions. They also observed a 4% occurrence of worsening of severity grades (40).

Van Rooij et al presented their 12 year experience with DAVF in article published in 2007 (41). Among their cohort of 91 patients a third of whom had CVR and two thirds presenting with hemorrhage, spontaneous thrombosis of DAVF were noted in 2 cases both of whom had presented initially with hemorrhage.

Strom et al (2009) published comparative study of 28 patients presenting with severe symptoms (ICH & NHND) 17 vs asymptomatic to minimally symptomatic patients 11, having the same Borden grade 2&3ie with cortical venous reflux (42). In the 17 asymptomatic or minimally symptomatic presentation group the incidence of new ICH was 5.7% with 0% new NHND over a period of 31.4 months, whereas the 11 patients that presented with symptomatic CVD had a cumulative event rate of 45% during the follow up period of 9.7 months itself which accounted for a statistically significant corrected annual rate of 1.4 % against 19%.

A natural history study published by **Bulters** et al in 2011 in 75 DAVFs followed up with partial or no treatment found that Borden or Cognard classifications were poor predictors of future hemorrhage, the only exception was Cognards type 4 fistulae which present venous ectasia (43). The presence of ectasia conferred a 7 fold risk of hemorrhage in comparison to those without. The other major predictor of poor outcome by this study was severity of index presentation with, hemorrhage or NHND as the initial presentation having a poor outcome in due course of time.

3.6 Treatment:

Treatment goals for these lesions may be palliative or therapeutic depending on presentation and natural history and includes endovascular, surgical and radiosurgical options or a combination of thereof. Conservative management (which involves no endovascular or surgical intervention with optional interval radiographic surveillance) with manual compression of involved arteries like superficial temporal artery in front of the tragus and occipital artery behind the mastoid have been advocated by many groups. Spontaneous cure of lesion is reported particularly in cavernous sinus lesions, So conservative management option may be feasible in select cases especially if it is a

minimally symptomatic lesion with no obvious signs of cortical venous reflux and evidence of hypertension. **Higashida** et al reported in 1986 on 152 patients with direct and indirect CCF observed a 30% cure rate in indirect CCF patients (7 out of 23) to whom trial of cervical carotid and jugular compression was administered (44). In the following year 1987 **Halbach** et al attempted compression trial in 9 of their 28 patients of symptomatic transverse, sigmoid sinus fistulas and achieved cure in 22% and improvement in symptoms in another 33 % of patients (45). Nevertheless it is advisable to give trial of compression in only those lesions without an aggressive presentation or relatively benign angiographic aspect as there exists a real risk of aggressive turn of events during the interim waiting period. Radiosurgery has been described as a successful, however 1-3 years must elapse to achieve the desired result (46-48). Patient may develop new symptoms in the interim period so radiosurgery should not be considered as a primary modality of treatment for cranial DAVFs especially aggressive ones. Surgical treatment involves clipping of the malformation, surgical isolation of the involved sinus, or cauterization of involved vessels. Endovascular transarterial or transvenous embolization may be effective as well, either alone or in combination with surgical techniques. For lesions of the anterior fossa, treatment is exclusively surgical due to the easy accessibility of the ethmoidal vessels by craniotomy. **Agid** et al published an article in 2009 wherein they have elaborated the management of 24 anterior cranial fossa DAVFs (49). 11 patients treated by surgery had 100% occlusion following surgery although complication in the form of brain edema was noted in one of the patient. Another 11 patients treated by Transarterial glue embolisation by ophthalmic artery had 64% success rate, and the patients that failed the endovascular option was subsequently treated successfully by surgical disconnection without sequelae. In this study the authors have opined that ACF DAVF may have reasonable chance of cure by transarterial endovascular treatment if the

angiographic evaluation is showing good sized access vessels. Later studies as recently as in 2015 by Thomas Robert et al had reported the successful endovascular management of ACF fistula in 10 consecutive patients using mainly transarterial Onyx embolisation.

Other dural arteriovenous malformations, particularly of the cavernous, transverse, and sigmoid sinuses, lend themselves exclusively to endovascular treatment (50-53). As a general rule transvenous embolisation of dural fistula is advocated in those cases wherein transarterial approach could not be performed, e.g.: in skull base fistulae.

Endovascular treatment has come full circle with earlier transarterial particulate/liquid embolics to transvenous particulate/ liquid embolics and with the availability of Onyx back to transarterial embolisation. Ethylene-vinyl alcohol copolymer (EVOH), dissolved in the organic solvent dimethyl sulfoxide (DMSO) and mixed with micronized tantalum powder to provide fluoroscopic visualization (Onyx; ev3, Irvine, California), is a liquid embolic agent that was granted Humanitarian Use Device exemption approval of the FDA for the presurgical treatment of central nervous system pial arteriovenous malformations in 2005. Its application in the endovascular treatment of intracranial AVMs was first described by **Taki** et al in the early 1990s, followed by other larger studies (11). The product used by Taki was called Ethyl Vinyl Alcohol copolymer (EVAL). Onyx is slightly different from EVAL in that, although both utilize the diffusivity of DMSO for precipitation, EVOH uses anhydrous DMSO. The product also contains finely powdered tantalum for radiopacity. The product therefore requires vigorous agitation in a mechanical shaker for at least 20-25 minutes. to keep the particles in a homogenous suspension prior to use. Same is achieved by "Vortex genie shaker" provided by the manufacturer. Once the embolic comes out of the catheter the DMSO diffuses away and EVOH in contact with blood solidifies as a thin skin along the contact interface while the

core remains liquid like molten lava. As the embolic injection continues more liquid comes to the centre and then solid outer lining ruptures at places and exposes more embolic to the blood and the cycle repeats over and over again as the embolic finds its way into unfilled vascular spaces. This has chiefly 3 advantages. First the rate of injection can be slow and controlled as there is less risk of catheter getting glued in, as the core of the onyx cast remains fluid. Second, if the embolic proceeds in an unintended pathway, injection can be temporarily halted and subsequently resumed till embolic permeates in a more desirable fashion. Third the embolic can be made to reflux into multiple confluents from a single pedicle injection. A unique property of Onyx is also its cohesive nature which allows it to percolate in a continuous file with no gaps in between which gets filled by clots and fibrin (This was implicated as a major shortcoming of acrylic embolics leading to frequent late recanalization in successfully embolized intracranial vascular malformations). A variety of DMSO compatible microcatheters are used to deliver the liquid embolic. Different density formulations of Onyx are available, with a lower viscosity version of the copolymer resulting in increased fluidity and thus further distal penetration into the lesion and a higher viscosity version of the product resulting in a more viscous liquid more suited for rapid polymerization for use in say a larger rapidly shunting fistulous communication. Onyx potentially combines the positive attributes of multiple other embolic agents, allowing distal penetration, like PVA particles, and providing permanent durable occlusion similar to that in *n*-BCA. Recently, some authors reported high rates of complete obliteration of DAVFs via transarterial approach using Onyx (5, 54, 55). The distinct characteristics of Onyx compared with *n* Butyl Cyano acrylate improve the likelihood of obtaining angiographic occlusion of a DAVF through a single pedicle injection. As far as transarterial embolisation of DAVF are concerned, the cohesive property of Onyx permits discontinuous injections on the order of several minutes and allows serial angiographic

analysis of the angioarchitecture of the lesion. In particular, small collaterals not visualized on initial angiography may become apparent with progressive infusion of Onyx. The ability to stop the infusion and to analyze the progression of the Onyx can minimize complications from unwanted infusion of the embolysate into potentially dangerous anastomoses or collateral network. The ability of Onyx to diffuse enables deeper penetration and occlusion of the fistulous network, and it can migrate retrograde into arterial feeders from other vessels when injected through a single pedicle itself. Venous filling can be stopped temporarily without the threat of unintended migration of the Onyx into draining veins. These advantages allow exceptional control of the flow of Onyx and enable a large volume to be delivered via a single injection. The caveats used in embolizing cerebral AVMs are less relevant when treating DAVFs. Injection of a large volume of embolic substance during treatment of an AVM can cause normal perfusion pressure breakthrough and subsequently ICH. Embolization of DAVFs is not associated with this risk.

Rezende et al reported the first successful case of DAVF embolization using Onyx without the need for any adjuvant surgery in a sphenoid wing DAVF in a technical note published in 2006 (56). Since then embolization of DAVFs have been one of the leading off label uses of Onyx.

In 2013, **Rabinov** et al published a comparative study of Onyx versus NBCA in treatment of 53 patients with 56 DAVFs and noted that, Onyx embolisation had a statistically significant initial as well as durable midterm angiographic cure of the lesion when compared with use of nBCA for the same indication (57). **Choo et al** (58) published their 17 year results in 2015 comparing results of Onyx versus glue and coils in treatment of DAVFs in which they have shown a statistically significant chance of lesions embolized with Onyx not requiring further treatment with alternative modalities like surgery (82% of

onyx treated patients did not require further treatment whereas on 22% of patients treated with glue did not require subsequent treatment. The rate of complications were also low with Onyx , however statistical significance could not be demonstrated because of low number of patients).

Few authors have noted the increased rate of complete occlusion using the middle meningeal artery as a single pedicle injection. MMA provides a route for the delivery of Onyx to occlude the fistulous point and retrograde artery to fistula to artery occlusion of arterial feeders. Similarly high rate of complete occlusion has been noted for DAVF with isolated drainage into leptomeningeal veins. In the only study published from India in this direction **Saraf** et al in their series of 99 patients from KEM hospital Mumbai had noted a cure rate of 87% using different endovascular methods and cure rate 92% for transarterial Onyx embolisation alone (59). They had also noticed incidence of 14 complications overall in which only 2 were attributed to the Onyx only group. In their retrospective analysis of 25 patients published by same authors anatomic cure was achieved in a single session and through a single arterial pedicle injection in 21 patients (cure rate of 84%). One patient showed angiographic cure on follow up angiogram obtained at 3 months. There was only one recurrence at the end of one year who was re-embolized successfully with Onyx. Complications were seen in two patients.

Key issues with transarterial onyx embolization as far as achieving angiographic cure in a given patient are distal migration of embolic into the venous system and proximal reflux of embolic along the pedicle being embolized. The former situation usually associated with high flow fistulae, leads to premature compromise of the venous outflow that may cause periprocedural hemorrhage or other venous embolic complications. patency of dural sinuses is to be maintained if these are noted to be draining the normal brain parenchyma during competitive angiograms. The second situation often

encountered during transarterial embolisation may force premature termination of embolisation procedure prior to satisfactory shunt disconnection. Usual get around for these is to use higher density EVOH (Onyx 34) suspension either during the initial part of the procedure alone or exclusively throughout the procedure. Distal flow control or venous protection may be offered in the form of temporary inflation of compliant balloons within the involved sinus segments or even stenting across the involved segment of the dural sinus prior to transarterial injection of embolic material. Another method frequently used is to attain flow control proximal to site of embolisation by using supplementary embolics like, glue, coils, Balloons. These procedures in addition to producing proximal flow arrest also prevent or limit the proximal reflux of the Onyx along the catheter shaft. The standard operating procedure when faced with proximal reflux is to temporarily discontinue the Onyx injection and to restart after a few ten seconds in the hope that the embolic may percolate antegradely into more favorable track, however if that is not the case to be, further continuing the embolisation may risk microcatheter retrieval difficulty with occasionally tip getting stuck in glue cast and rupture of microcatheter during attempted forceful retrieval. It also results in loss of large amounts of precious embolic material as proximally refluxing embolic material does not contribute to shunt disconnection. **Shi** et al reported in 2013 on various adjuvant flow control techniques used by them in endovascular treatment of DAVF using Onyx in 84 embolisation sessions (60). These included distal flow control methods during transarterial and transvenous onyx embolisation using coils in the venous side, proximal flow control using coils or high concentration glue during transarterial onyx embolisation, arterial and venous sided "Balloon assisted techniques " during arterial and venous Onyx embolizations. The authors have claimed that despite the fact that the treatment sessions were undertook in rather difficult cases wherein straightforward embolisation sessions would seem markedly

difficult or impossible to perform the complication rates in their series with assisted techniques were comparable to their result in Onyx only subgroup of patients (19.4. versus 17.6 %).

Over the last few recent years many new innovative transarterial Onyx embolization methods have been evolved by various operators. These include the ‘pressure cooker technique’, the use of dual lumen balloon catheters for simultaneous liquid embolic permeation and achieving flow control at the same time. Even percutaneous puncture of transosseous feeders and direct instillation of onyx has been put forth as a safe and stable mechanism for treatment of cranial DAVFs. **Chapot** et al described the first cases of transforaminal endovascular treated case of DAVF in 2007 in four patients where he used a percutaneous access to diploic channel in skull in occipital region as conventional transfemoral approach was rendered impossible due to extreme tortuosity (61). **Saura** et al reported in 2013 regarding 4 case of transforaminal onyx injections for successful treatment of DAVFs (62). The puncture in these cases were made with a 25 G butterfly needle with an attached microbore tubing to directly inject onyx via a fluoroscopy assisted targeting of 3D CT localized emissary and diploic foramina.

3.7 Results of treatment:

A retrospective review article published from Barrows Neurological institute in 2010 by **Hu** et al , the authors reported an angiographic cure of 79% when transarterial onyx along with supplemental embolics were used and 83% when onyx alone was used transarterial in the treatment of 41 patients with 50 DAVFs when evaluated at a median of 5 month period (63). The group also found out that using MMA as a conduit to deliver Onyx met with higher chance of successful angiographic cure. In this series they have reported a complication rate of 8% out of which only 2% was a permanent. **Chandra** et al

in 2014 published their results of transarterial Onyx embolisation of 40 consecutive patients with 41 fistula with intermediate and long term follow up (64). Their primary angiographic cure rate was higher at 95% with similar complication rate of 9% (out of which again permanent complication was only 2 %). There was a 6 % short term (mean of 4 months follow up) recurrence . However none of their patients with a long term follow up of 117 patient years (mean follow up period of of 45 months) had experienced any hemorrhagic episodes. **Castilla** et al who also published in the same year 2013, their results of endovascular management of DAVF with Onyx, a majority of which was transarterial (57% arterial , 29 % combined arterial and venous and 14% venous alone with or without standby supplemental embolics like coils, stents or glue) in 63 DAVF in 53 patients achieved a angiographic cure of 92% which in their midterm and long term follow up showed up to be 100% stable at 6 months and 92 % stable at the end of 46 months . They also reported a complication rate of about 10%.

3.8 Complications

In the initial experience by **Taki** himself (11) and also by **Taki and Sadato** (65) recanalization of lesions, that is the pial malformations and angioneclerosis of vessels observed at surgery was common problems. This was later shown to be related to DMSO content and it was later demonstrated by **Chaloupka** and **Murayama** (66-68) that DMSO toxicity could be avoided if DMSO volume administered prior to onyx injection was limited to the dead space of the catheter and by prolonged slow injection of embolic lasting more than 60 seconds. Blackish discoloration of skin of scalp may persist for many years after the procedure; however it may fade out somewhat with time. Trigemino cardiac reflex is a known complication with embolisation of cavernous region DAVF. Extrusion of Onyx

debris percutaneously following the embolisation may be noted and has been reported previously.

Rerouting of venous drainage may occur during embolisation especially if the venous outlet is compromised before complete fistula disconnection is attained, may lead to rerouting of flow to the ophthalmic veins, cavernous sigmoid region, into perimedullary veins causing orbital signs and symptoms, tinnitus and myelopathic changes respectively. There may also be worsening of fistula grade, like worsening or de novo appearance of CVR where none existed prior to treatment. Inadvertent closure of venous outlet may also result in ICH. Therefore any seizure occurring following the embolisation for the first time should always prompt CT evaluation for possible hemorrhage. The Gluing of microcatheter has become less of an issue with Onyx and development of detachable tip microcatheter, however may still happen. In fact an accusation leveled against Onyx is that it induces in the operator a false sense of security leading to Gluing in of catheters.

MATERIALS AND METHODS

This is a retrospective and prospective study by analysis of neurointerventional radiology database of SCTIMST of those patients with adult type of brain dural arterio venous fistula, who underwent embolisation with Onyx between Jan 1st 2010 and 31st May 2015. Angiographic predictors of complete occlusion of shunt by transarterial embolization and its clinical and imaging correlates were attempted to be deduced from the said data and inferences made in accordance. Attempt was also made to evaluate clinico- radiologic characteristic correlation, efficacy of transarterial onyx embolization of adult type DAVF, technical appraisal of embolization, enumeration of complications and technical difficulties encountered during these procedures. The patients were evaluated after procedure by clinical examination at routine intervals. Patients were also scheduled for follow up cerebral angiogram.

Total number of patients that underwent procedure was 44. One patient expired in post op period (poor GCS at admission), yet another patient with a failed embolisation of extensive trans spatial dural fistulae died 18 months due to unrelated issues (HIV positive with pulmonary TB). The first of these two patients were not included in the further analysis of the data, whereas the second patient was included in technical analysis of procedure conducted on him. The final patient cohort consisted of 34 males and 9 females with 75 fistulae in total. 49 embolisation sessions were performed in all, including two sessions for different lesions in the same patient in 5 instances. In one of these instances the embolisation sessions were carried out in the same sitting. Two patients received repeat embolizations one more time each for previously treated residual/ recurrent lesion.

All patients underwent thorough physical examination including neurologic evaluation at presentation and post procedure prior to discharge. Patients also had baseline

radiologic investigation by cross sectional imaging. Demographic and clinical data of patients were collected from clinical charts and Outpatient files from Medical records division. Patients underwent through cerebral angiograms before definitive management in all elective cases. All the studies were performed on Innova biplane flat panel digital subtraction angiography unit (GE Milwaukee, USA).

The diagnostic angiographic studies were retrieved from Neuro radiologic archives and analyzed for angiographic predictors of complete embolisation and correlation with clinical presentation and outcome following treatment.

Follow up of patients was done at 1 month and 3 months clinically and at 6 months clinically and radiologically. Radiologic follow up by DSA was scheduled in all cases and were available in 29 instances. Follow up data from all patients were obtained from hospital case records, during their OPD visits and by telephone conversation with patients or their relatives.

All 6 vessel diagnostic angiographies were undertaken under local anesthesia only when they were done with a non therapeutic intent for example as the initial diagnostic tool and then for check angiography during follow up imaging. All Therapeutic/ interventional procedures on the other hand were exclusively performed after inducing general anesthesia. Parenteral premedication with Inj. Pethidine 25 mg & Tramadol 50 mg was administered prior to procedures performed under local anesthesia. In all cases of diagnostic angiographies the patient was admitted to ward or step down ICU for overnight monitoring of puncture site as well as vital signs. When interventions under GA were done the patients were admitted to dedicated neuro intervention intensive care unit and monitored for 48 hours followed by further observation in the step down unit for another 48 hours prior to discharge. At the end of 96 hours post op, the patient was discharged if not otherwise indicated.

Subsequent patient follow up was by scheduled IR OPD visits at 4 weeks and then again at 3 months, when through clinical evaluation was made and documented on OPD sheets. Patients that underwent successful treatment were further scheduled for angiographic confirmation of shunt exclusion after 6 months of treatment. Patients with poor or inadequate results were scheduled for earlier angiographic evaluation at times.

A complete evaluation of the patient including demographic profiles (age, sex), clinical presentation, imaging features, treatment method and outcome including complications and follow up was carried out as per the proforma attached.

4.1 Technique of embolisation:

All procedures were performed via the transfemoral route using the Seldinger technique. All cases were done under general anesthesia and under systemic heparinization (Heparin 3000- 5000 IU as bolus and 1000 IU every hour monitoring of activated clotting time) to maintain ACT between 200 to 300 seconds (Actalyke MINI 11, Helena Laboratories). The guiding catheters were placed in the proximal ECA or in proximal VA. Microcatheters (flow or wire guided) were placed in the appropriate arterial feeder as proximal to the fistulous communication as possible. Guide sheaths and microcatheters were continuously flushed with heparinized saline. After confirming safe location by superselective microcatheter injection, Onyx embolisation was commenced and performed to its logical conclusion. A post procedure Dyna CT was performed on table.

4.2 MATERIAL USED FOR ANGIOGRAM AND EMBOLIZATION

- 1) Arterial Sheath – 6 & 7 French size Radiofocus, Cordis
- 2) Diagnostic catheters – 4, 5 & 6 French Vertebral glide (Terumo), Right coronary (Cordis), Simmons 1 (Cordis), multipurpose.

- 3) Guide wire – Terumo exchange length 260 cm, Terumo standard 150 cm ,
- 4) Guiding catheters/sheath –5F slip cath, 6, 7, 8 French size Long sheath (COOK), Envoy(Codman), Neuron/ Neuron maxx (penumbra) , Chaperon (Microvention)
- 5) Microcatheters –Marathon 10, Echelon 10, Rebar 18, Apollo 10 (ev3), Sonic (Balt).
Sonic and Apollo were tip detaching microcatheters.
- 6) Microguidewires-Mirage 008 (ev3), Hybrid 007 wire (Balt), Traxcess014 (Microvention), Transcend 010, 014, (Boston scientific). (190-205cm)

4.3 STATISTICAL ANALYSIS

All statistical analysis was done using SPSS software version 17 (SPSS Inc. Chicago, IL, USA). The significance levels of all tests were set at $p < 0.05$ and were two sided.

For evaluation of clinical, imaging and treatment characteristics, a frequency distribution table of relevant criteria was first made. The discrete variables were studied against the clinical presentations and strength of association tested with Chi square test. The continuous variables were also assessed and studied by comparison of means using ANOVA.

The treatment outcomes were classified as a binary outcome and Chi square test was again used to assess the strength of association with discrete variables in demographic, clinical, angiographic and specific procedural domains and student's t- test was used for comparing the means of quantitative parameters. The variables that were identified to have a statistically significant association on univariate analysis was subjected to a multiple logistic regression analysis to see if any of these were independently predictive of complete occlusion by transarterial onyx embolisation.

RESULTS

Table 4 : (a) Age frequency by the decade; (b) Age frequency by Class Distribution

4 (a)

Age range (by decade)	Frequency
0-10	0
11-20	1
21-30	4
31-40	12
41-50	14
51-60	9
61-70	2
71- 80	1

4 (b)

AGE		
	Frequency	Percent
0-30	5	10.2
31-60	41	83.7
61 -90	3	6.1
Total	49	100.0

Figure: 1 Histogram showing age distribution in cases

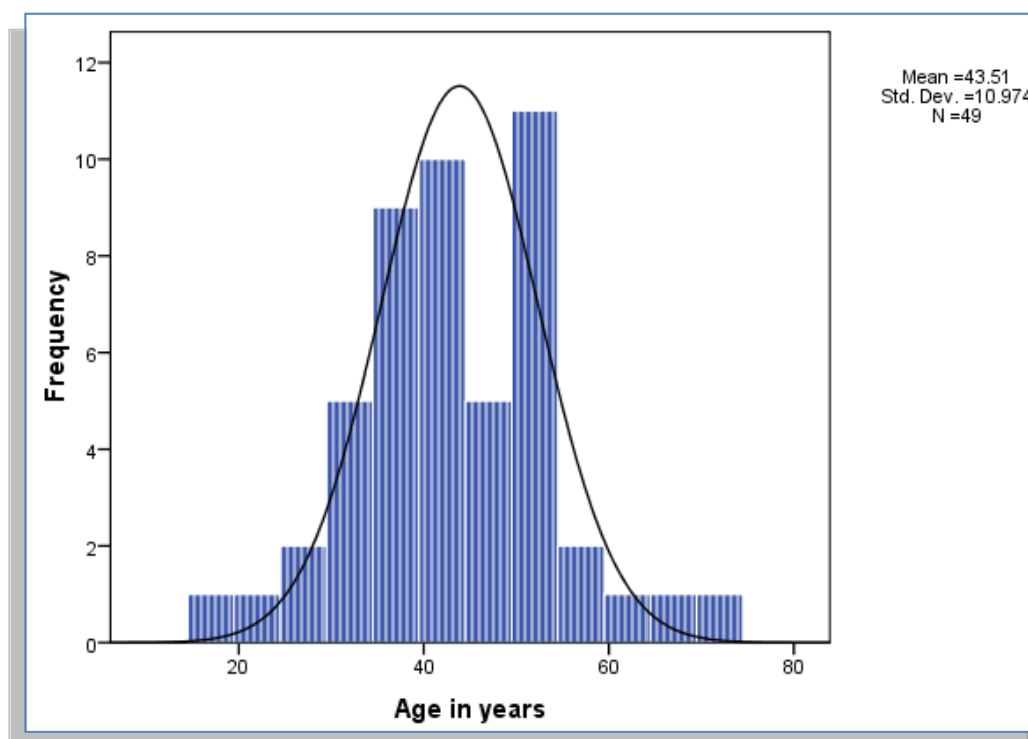
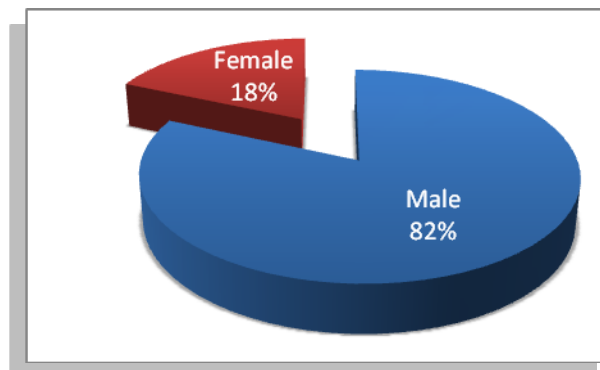
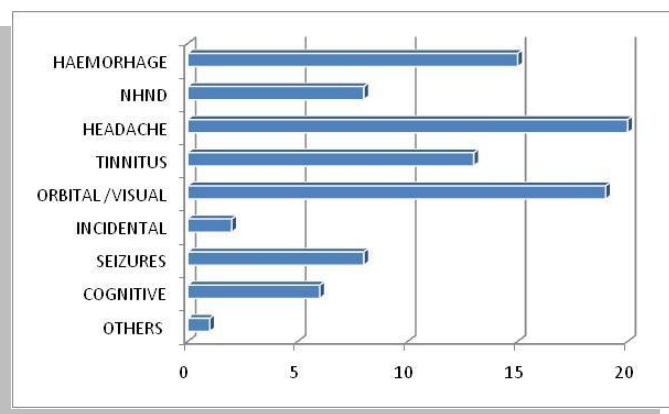


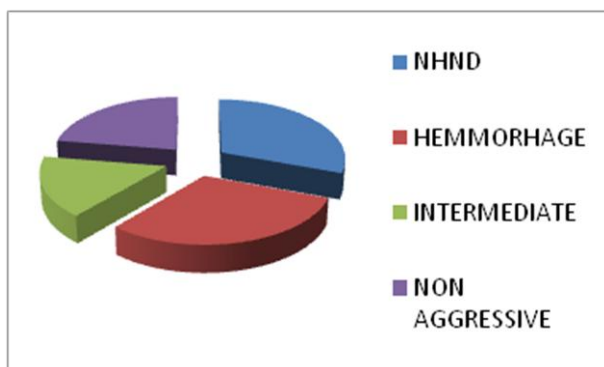
Figure: 2 Pie diagram showing distribution of gender among cases**Table 5:** Distribution of Clinical presentation

PRESENTATION	FREQUENCY(%)
HAEMORHAGE	15 (31%)
NHND	8 (16.3 %) [excluding progressive visual loss and cranial nerve deficits)Motor, sensory, posterior fossa, speech, gait]
HEADACHE	20(41 %)
TINNITUS	13 (26.5 %)
ORBITAL /VISUAL	19 (38.7 %) [progressive visual loss 7 + CND 3 +other 9]
INCIDENTAL	2 (4 %)
SEIZURES	8 (16.3%)
COGNITIVE	6 (12.2 %)
OTHERS	1

Figure: 3 Histogram of presenting complaints**Table: 6** Statistically significant correlations between Clinical presentation, Demographic and Angiographic variables

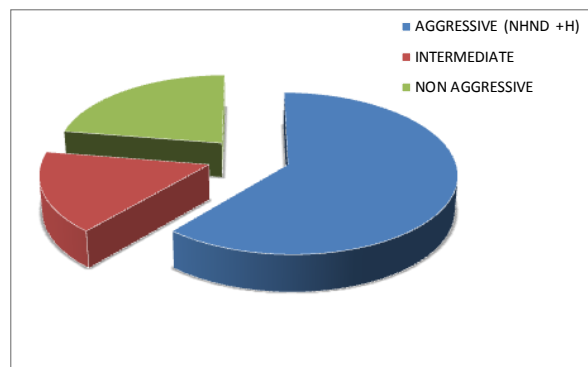
Attribute	NHND	H	I	NA	p VALUE
Mean time to Dx (mths)	12.8(13.8)	5.3(8.3)	8(7.2)	11(23.09)	0.012
Initial MRS (1/2/3/4)total	(1/6/6/2)15	(4/6/2/3)15	(3/3/1/1)8	(8/3/0/0)11	0.043
6 month MRS(0/1/2/3/4)total	(3/3/4/5/0)15	(14/0/1/0/0)15	(4/0/2/1/1)8	(8/2/0/0/1)11	0.005
Multiplicity %	67	33	50	27	0.016
Midline	11/15(73%)	2/15(13%)	3/8(37.5%)	3/11(27.3%)	0.007
Borden (B1/B2/B3)total	(0/11/14)15	(0/7/8)15	(1/6/1)8	(2/2/7)11	0.032
Venous ectasia present %	20	67	0	36	0.006
Out flow restriction present %	100	73	88	54	0.033

Figure: 4 Presentation



Category	Count	Percentage
NHND	15	30.6
HEMMORHAGE	15	30.6
INTERMEDIATE	8	16.3
NON AGGRESSIVE	11	22.4
Total	49	100.0

Figure: 5 Aggressiveness



Category	Count	Percentage
AGGRESSIVE (NHND + H)	30	61.2
INTERMEDIATE	8	16.3
NON AGGRESSIVE	11	22.4
Total	49	100.0

Figure 6: Multiplicity of lesions

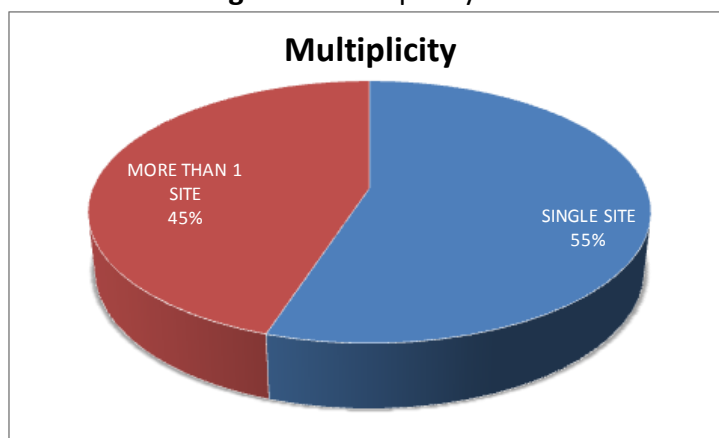


Table 7: Frequency of lesions- Location wise

Location	Number	Percentage
SSS TO TS-SS Jn	24	49
SS- IJV	3	6.1
TRANSPATIAL	2	4.1
MCF	1	2
CORTICAL VEINS	14	28.6
TENTORIAL	5	10.2
Total	49	100

Figure: 7 Pie chart of topographical distribution

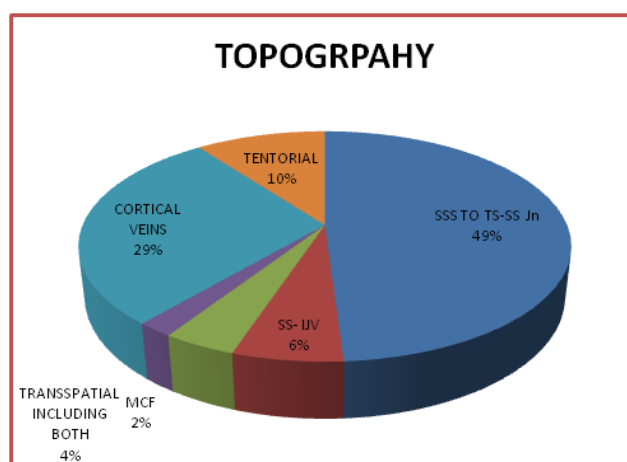


Figure 8: Arterial Supply

(a) External Vs Internal (b) Unilateral Vs bilateral (c) Side (d) Anterior Vs Posterior

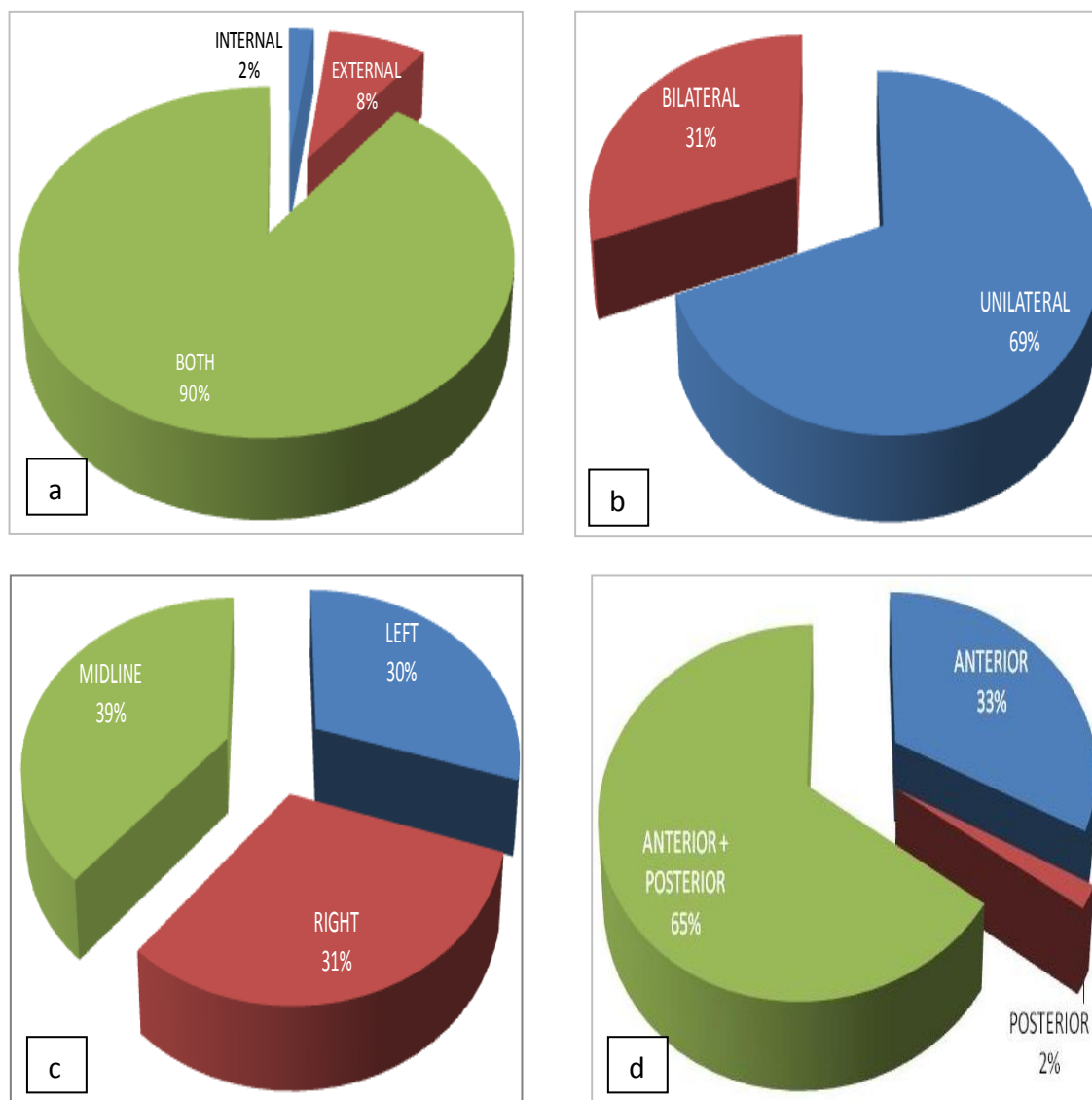


Figure: 9 Distribution – Embryology wise

Table 8: Embryological classification frequency

EMBRYOLOGIC TYPE	NUMBER	%
DE	37	75.5
VE	3	6.1
LE	5	10.2
DE +VE	4	8.2
Total	49	100.0

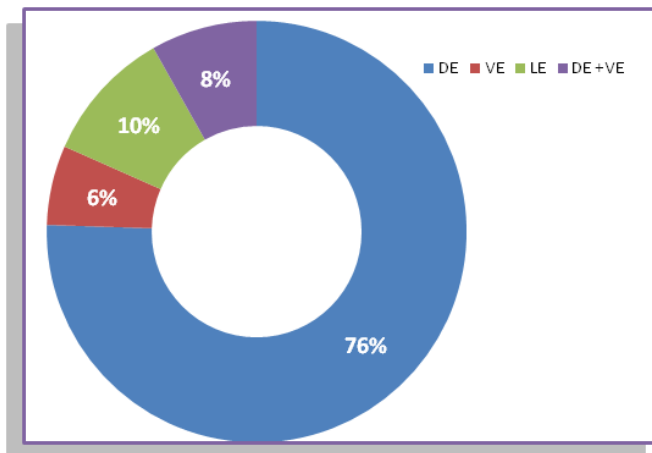


Figure: 10 Distributions – Borden Class

Table 9 : Borden Classification

BORDEN CLASS	NUMBER	PERCENTAGE
B1	3	6.1
B2	26	53.1
B3	20	40.8
TOTAL	49	100.0

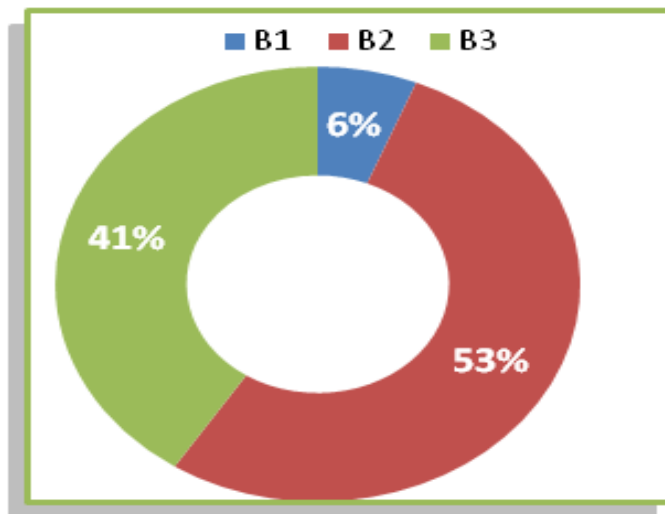


Figure: 11 Distributions – Cognard Class

Table 10: Cognard's Classification

COGNARD TYPES	NUMBER	PERCENTAGE
TYPE1	1	2
TYPE 2A	3	6.1
TYPE 2B	4	8.2
TYPE 2 A+B	26	53.1
TYPE 3	8	16.3
TYPE 4	7	14.3
Total	49	100.0

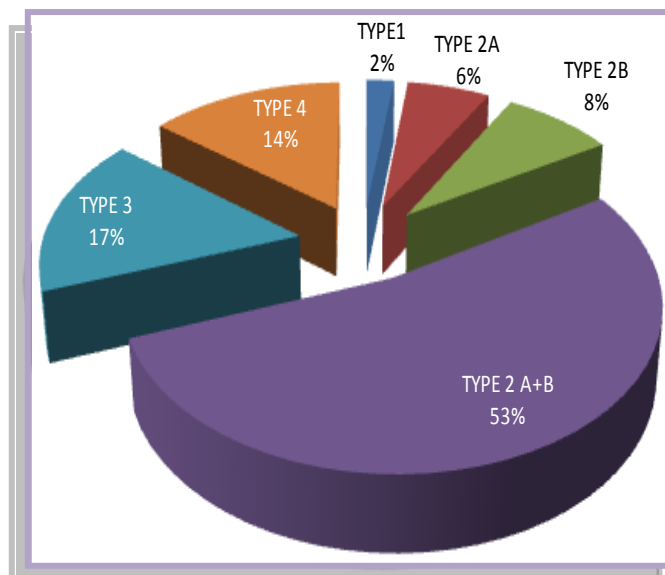


Table 11: Treatment Outcome vs Demographic, Angiographic and Treatment variables

Variable	Total(success)	Incomplete(failure)	P value
DEMOGRAPHIC			
1. AGE mean	43.98(11.59)	40.71(5.88)	0.270
2. SEX (M%/F%)	82/100	8/0	0.179
3. C/F (NHND/H/I/NA)	9/14/8/11	6/1/0/0	0.007
4 . AGGRESSIVENESS (A/I/NA)	23/8/11	7/0/0	0.075
5 INITIAL MRS (1/2/3/4)	15/15/6/6	1/3/3/0	0.204
6. DM %	19	28.5	0.441
7.CVT %	14.3	28.5	0.320
8. DURATION MEAN INMONTHS	11.09(14.21)	17(17.38)	0.42
ANGIOGRAPHIC			
1.RIGHT %	50	71	0.263
2. LEFT %	43	43	0.663
3.MIDLIN %	33	71	0.069
4.MULTIPLICITY %	38.1	85.7	0.025
5. ECA/ ICA(E/I/E+I)	4/1/37	0/0/7	0.629
6. U/L VS B/L (UL/BL)	26/16	4/3	0.561
7.LATERALITY(L/R/M)	14/12/16	1/3/3	0.564
8.ANT vs POST (A/P/BOTH)	14/1/27	2/0/5	0.880
9.CIRCULATION TIME (SECONDS)	7.64(3.31)	7.64(2.56)	1.00
10. EMBRYOLOGIC CL(D/V/L/D+V)	31/3/5/3	6/0/0/1	0.61
11.BORDEN (1/2/3)	3/21/18	0/5/2	0.517
12 COGNARD(1/2A/2B/2A+B/3/4)	1/3/3/22/6/7	0/0/1/4/2/0	0.702
13 DES			
Directness %	40	33	0.56
Exclusivity %	35	16.67	0.35
Strain %	80	83	0.667
14.CVR %	95	100	0.73
15. VENOUS HYPERTENSION %	71	85.7	0.392
16. VENOUS ECTASIA %	28.6	14.3	0.392
17.OUTFLOW RESTRICTION %	76	100	0.179
TREATMENT VARIABLES			
1.ONYX MEAN VOLUME (CC)	3.27(2.97)	1.73(1.48)	0.046
2.ONYX INJECTION TIME(mts)	55.88 (28.03)	39.43(30.24)	0.216
3.SUPPLEMENTAL EMBOLIC %	23.25	50	0.009
4 EMBOLISED FEEDER (mma/ mma+oa)	40/3	3/3	0.019

Table 12: Analysis of Endovascular Treatment through MMA

QUATITATIVE RX VARIABLES	ANGIOGRAPHIC RESULT	N	Mean	Std. Deviation	p value
DURATION(MONTHS)	TOTAL / NEAR TOTAL	43	10.83	14.08	0.437
	INCOMPLETE	6	15.83	18.73	
NO OF LESIONS	TOTAL / NEAR TOTAL	43	1.58	1.159	.082
	INCOMPLETE	6	2.50	1.38	
CIRCULATION TIME CALCULATION	TOTAL / NEAR TOTAL	43	7.814	3.4607	.703
	INCOMPLETE	6	7.250	2.5642	
ONYX IN ML PER MMA FEEDER	TOTAL / NEAR TOTAL	43	3.10	2.272	.080
	INCOMPLETE	6	1.60	1.617	
SIZE OF MMA FEEDER IN MM	TOTAL / NEAR TOTAL	41	1.47	.823	.354
	INCOMPLETE	5	1.12	.327	
MMA ONYX INJECTION TIME	TOTAL / NEAR TOTAL	43	52.95	25.93	.115
	INCOMPLETE	6	34.33	31.61	
DISTANCE OF CATHETER TIP	TOTAL / NEAR TOTAL	40	2.35	2.636	
	INCOMPLETE	6	24.72	33.74	.165
FEEDER LENGTH DISTAL TO SKULL BASE	TOTAL / NEAR TOTAL	43	107.87	41.43	.858
	INCOMPLETE	6	111.05	32.4	
BENDS AP	TOTAL / NEAR TOTAL	43	4.44	1.532	.13
	INCOMPLETE	6	6.17	2.317	
BENDS LATERAL	TOTAL / NEAR TOTAL	43	4.53	1.667	.023
	INCOMPLETE	6	7.33	2.160	
TOTAL BENDS	TOTAL / NEAR TOTAL	43	8.98	2.816	.021
	INCOMPLETE	6	13.50	3.391	

Table: 13 DES Classification (a) According to most severe lesion (b) According to lesion treated at each instance

(a)			(b)		
DES(SEVERITY)	NUMBER	PERCENTAGE	DES (Rx)	NUMBER	PERCENTAGE
NO CVR	3	6.1	NO CVR	3	6.1
nDnEnS	5	10.2	nDnEnS	8	16.3
nDnES	14	28.6	nDnES	14	28.6
nDES	4	8.2	nDES	5	10.2
DnEnS	2	4.1	DnEnS	0	0
DnES	7	14.3	DnES	8	16.3
DEnS	4	8.2	DEnS	1	2.0
DES	10	20.4	DES	10	20.4
Total	49	100.0	Total	49	100.0

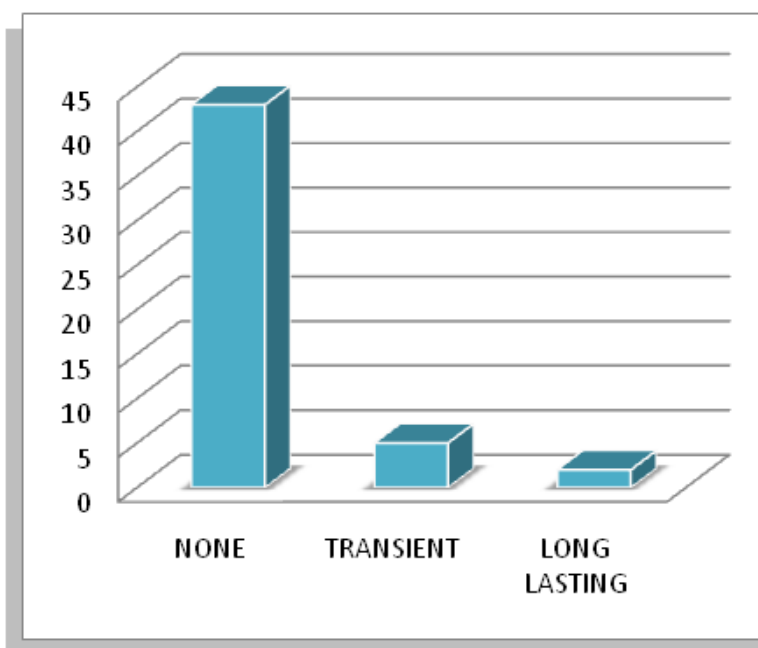
Figure: 12 Procedure related complications

Figure:13 (a) Objective outcome : Initial Vs 6 months MRS
 (b) Subjective outcome : Initial Vs 6 months

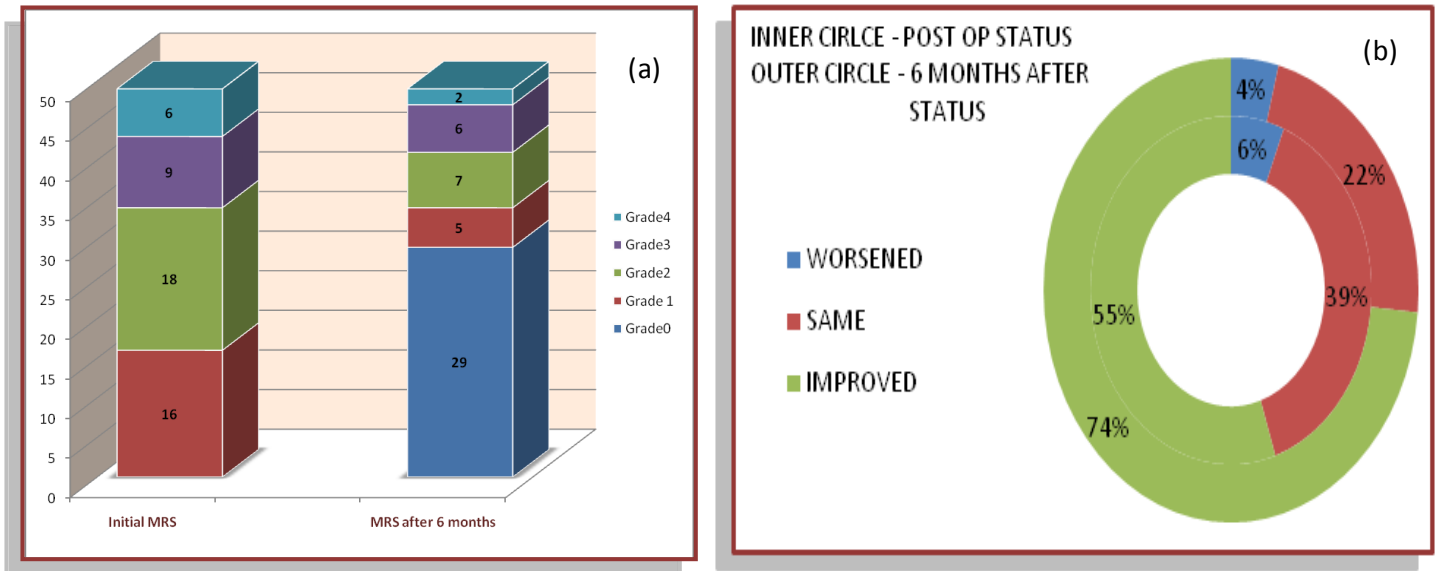
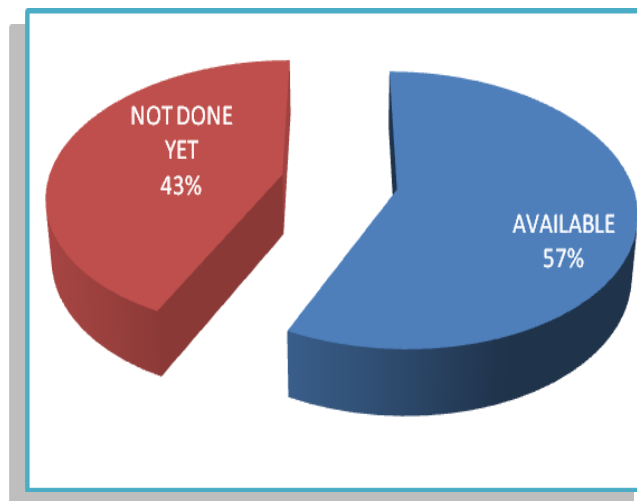


Figure:14 Follow Up by Angiogram



DISCUSSION

The current study undertaken at SCTIMST was an attempt to study the clinical and radiographic features (chiefly angiography) of adult type of dural arteriovenous fistula, to analyze the transarterial Onyx embolisation procedures undertaken in these patients with intent to obtain a cure when possible or palliate at other times. The study purported to assimilate data regarding the unique disease pattern in the country, wherein according to our knowledge there is only a single study published from KEM Mumbai in this direction. The study also attempted to look for possible links between angiographic characteristics and the clinical phenotype as well as efficacy of treatment via transarterial onyx embolisation. Study was started after obtaining IEC clearance form SCTIMST vide letter SCT/IEC-486/July 2013 dated 29/7/2013 and included patients of adult type of DAVF treated by transarterial onyx injection at SCTIMST between first of January 2010 to thirty first of May 2015. Thus the study comprised of a prospective cohort of 31 patients embolized prior to 29/7/2013 as well as retrospective cohort 18 patients embolized prior to the said date of IEC clearance. 5 patients planned for transarterial embolisation with Onyx were excluded from the study. Four of them had spontaneous thrombosis of incriminated lesions and one patient who presented with hemorrhage in (MRS-5) could not be salvaged despite emergency intervention and expired shortly thereafter.

- ☑ A total of 43 patients, 34 males and females were included in the study. In 43 patients there were a total of 75 fistulae for which 49 embolisation sessions were undertaken. Two Onyx sessions each were undertaken in 6 patients for different lesions at separate occasions. In 3 out of the 6 cases the second attempt of previously treated site following persistence or worsening of symptoms after failed initial attempt. In three others the second session was done to address a different

lesion following worsening or new symptoms. One patient with severe symptoms was treated for two lesions in the same sitting. Out of the three instances of retreatment 2 lesions were completely cured and 1 lesion was still uncured.

- ☑ Age of our patients ranged from as young as 17 years to as old as 74 years with median age of 43.14 +/- 22.76. The maximum number of patients -14 (32.5 %), nearly a third were in their fifth decade of life. There were no patients in their first decade of life and there was only one patient in second decade. Overall, in 84% instances in our study the patients were in the 3rd to 6th decade of life (31- 60 years). 10% of the cohort was in their first three decades and 6% in 6th to 8th decade (60 to 90 years). In the recently published study by **Chandra** et al (64) in 41 patients of DAVF treated by transarterial onyx embolisation the mean age was 57 years (range, 30–79 years). In a similar but more recent study by **Castilla** et al in 53 consecutive patients, mean age was 56±16 years (range 18–84) (69). In a consecutive study of 25 patients reported from India treated **by Saraf** et al (59) the age range was similar to the present study that is 12-68 years. This may be due to the discussed aetiology of DAVF as an acquired rather than a congenital disorder.
- ☑ Our patient groups comprised of 34 males (79%) and 9 females (21%), almost 3.8: 1 male preponderance (39 males and 10 females in 49 different instances). Chandra et al (64) reported a 1.1 : 1 ratio of males to females, whereas Castilla et al (69) reported a 2.1 :1 male preponderance. Saraf et al (70) reporting on their larger cohort of 99 patients of DAVF showed a 1.75 : 1 male : female ratio.
- ☑ Comorbidities: 27 patients in our group did not have any obvious comorbid illnesses whereas 16 patients had various comorbid illnesses. most common known comorbid illnesses included Diabetes mellitus (DM) and Cortical and dural sinus

venous sinus thrombosis (CVT) which was present in 6 patients (10 instances of DM and 8 instances of CVT) each giving an incidence of 14 % of each in our patient group. Presentation wise incidence of Dm & CVT were 20% and 16 % respectively, making DM the most frequently encountered co morbid condition. All cases of DM were males whereas there were 4 male and 2 females who were known case of CVT. In our patient group all though there were twice the number of males with previously known CVT compared to females, when looking at the picture as a whole, 2 out of 9 female patients; ie 22 % had CVT but only 4 out of 34 (11.8 %) of affected males had history of CVT previously. DM on the other hand was more prevalent in males at 18 % in comparison to 0% in females.

One commonly accepted etiology for development of DAVF is cortical and dural venous sinus thrombosis and therefore it may be presumed that women constitute the larger percentage of dural fistulae due to their propensity to have CVT in association with prothrombotic states of pregnancy, puerperium and oral contraceptive use. However, many of the reported series involving treatment of DAVF (59, 63, 69) reported an overwhelming male predominance like in present study. Multiple natural history studies dealing with aggressive lesions have likewise reported a male predominance similar to our study population). It was however noted that in keeping with the general trend prevalence of CVT itself was nearly double in the female cohort 22% versus only 12 % of the male cohort. The two female patients developed DVT following childbirth. There was yet another patient who had history of prolonged OCP use but never had a documentation of CVT prior to diagnosis of DAVF. In males with CVT one out of 4 had a history of surgical intervention (C5-6 discectomy) prior to development of CVT. It is to be noted here that 33 out of 43 patients (77%) demonstrated some form of stenosis or occlusion of one or more dural sinuses at angiography for diagnosis of DAVF, however

since a cause effect relationship could not be convincingly demonstrated in all, only the patients previously admitted and treated for possible or diagnosed CVT are included in the above analysis.

Lee et al (71) published his study in 2013 reporting on the association between DAVF and DM in 192 Korean patients with DAVF. He concluded that there exists a definitive association between DM and DAVF as evidenced by a 2.35 OR of diabetic patients to have DAVF in comparison to nondiabetic patient and also the diabetic patients tended to have higher angiographic grades and aggressive presentations both of which were also statistically significant. He postulates that this may be due to common pathology of dysregulated angiogenesis as occurring in diabetic retinopathy or nephropathy as well as in DAVF and further also implicates the abnormally high levels of expression of b FGF and VEGF in patients with both diseases.

In our study it was noted that overall incidence of DM was 16 % in patients but when the prevalence of DM was assessed in the total number of instances it rose to 20 %, because 4 out of 6 male patients that underwent 2 separate sessions were noted to be patients of DM as well. However any adverse effect of DM or CVT on treatment outcome was not statistically demonstrated in this study. It was also noted that overall prevalence of multiple fistula was 14 out of 43 (33%) and among the 9 female patients only one (11%) had multisite DAVF whereas all 6 (100 % of diabetic) male patients with DM had multi site DAVFs (patients had more than one lesion) and 5 out of 6 (83 % of diabetics) patients had aggressive presentation with NHND and 4 out of 6 (67 % of diabetics) patients had type 3 Borden fistula along with the other two having Borden type 2 lesions. In the present study 4 out of 27 instances (15%) of single site fistula and 6 out

of 22 (27%) cases of multi site fistula had DM additionally, which did not however show a statistically significant association.

On similar lines a history of CVT was present in 5/41 (12 %) of successfully treated cases and 2 /8 (40%) of failed cases. CVT was seen in 2/27 (25%) and 6/22 (27%) cases of single and multisite lesions respectively. These results were also not statistically significant ($p= 0.32$ for treatment outcome and 0.07 for multiplicity).

Other common comorbid illnesses included hypertension (HT) which was present in a total of 5 patients (4 males and one female) and associated dyslipidemia was seen in 3 out of 4 male patients with HT. Other comorbidities included coronary artery disease (CAD), Seizures, a history of trauma, human immunodeficiency viral infection (HIV), pulmonary tuberculosis (PTB), Lhermitte Duclos disease and osteogenesis imperfecta. Each of these were seen in one patient each, all of them males.

For this discussion we have included all cases of intracranial hemorrhage and progressive neurologic deficits including progressive visual decline as aggressive presentations. Progressive cognitive decline, dementia or other signs of congestive venous hypertensive encephalopathy like cerebellar signs, Parkinsonism and apathy were regarded as aggressive symptoms because they warranted an urgent if not an emergent intervention. Swaying to side while walking, vertigo and dizziness were attributed to posterior fossa neurologic deficits if imaging showed involvement of posterior fossa venous system. All fixed neurologic deficits of cranial nerves and seizures were not included in aggressive manifestations, however they are quite significant findings with profound impact on the health and well being to life even though may not be life threatening. Therefore these findings along with orbital symptoms including non progressive blurring of vision or reduced visual acuity, retro orbital pain, diplopia, swelling

of eyes, proptosis, conjunctival congestion, lacrimation were included as a group of intermediate severity. Orbital /visual symptoms that were transient like blurring of vision were counted as transient ischemic attacks if corresponding to vascular territory involved on angiographic analysis and then classified as a symptom of intermediate significance. Lesions that were incidentally picked up on imaging done for unrelated causes along with those presenting only with tinnitus or atypical headaches were grouped as non aggressive presentations. We have refrained from using terms “benign symptoms” for these as the interpretation of the symptom severity in these cases is quite subjective and may possibly be rather bothersome for the patient even though not having a severe impact on patient’s health at least in the immediate time period. All neurologic deficits, losses of consciousness, alteration of sensorium or seizure occurring immediately after a hemorrhage are not separately counted elsewhere as deficits. Headache, seizures or neurologic deficits in a patient that eventually bled prior to presentation were separately accounted for if those symptoms were present in those patients at least a week prior to the episode of hemorrhage. (Similar codifications of disease presentation severity were used by **Baltsavias** et al (**72**) in their four part article on DAVFs).

In our patient group of 43 there were 48 embolization sessions. One patient was embolized in 2 different areas with 2 different lesions in the same sitting (total of 49 instances). 5 patients were embolized in two different sittings. In two of those cases the embolization were electively planned and carried out as per schedule. In 4 cases there were worsening of symptoms or appearance of new symptoms (including progressive visual loss in one, progressive limb weakness in one, seizure, diplopia and new onset headache in one and progressive tinnitus and apathy in one).

Atypical headache was the most common presentation and was present in 20 out of 49 patient presentations (41%). Second most common complaint was orbital and visual complaints, which was seen in 19 of 49 patient presentations (38.7%). Orbital and visual symptoms consisted of 7 instances of progressive visual loss (14.3 % overall) which was considered as an aggressive presentation, 3 instances of diplopia (6%) of intermediate severity presentation and 9 instances (18.4%) of benign presentations. Hemorrhage was seen in 15 of 49 patient presentations in this study (31%). Intracranial hemorrhage presented typically as a sudden severe incident with associated headache followed by seizures, loss of consciousness or focal neurologic deficits in 10 out of 14 patients, In the other 4 patients hemorrhage was detected on cross sectional imaging (CT or MRI) when evaluated for presentation atypical for a hemorrhage like recurrent headache of 4 months duration in one patient, recurrent seizures and progressive loss of vision in another of 1 month duration, yet another presented with repeated headache, seizure and progressive dementia and parkinsonism of 1 month duration , One patient presented with sudden severe headache following alleged trauma to head. Next common symptom was pulse synchronous tinnitus which was seen in 14 patients (29%) which was counted as non aggressive presentation. Seizures were the presenting complaint in 8 out of 49 patient presentations (17 %). Non hemorrhagic neurologic deficits including limb weakness, sensory abnormalities, speech difficulties, gait abnormalities and posterior fossa signs and symptoms were next in frequency seen in 8 patients (16%) and counted as aggressive presentations. Neurologic symptoms involving the cognitive domain like apathy, dementia, altered behavior and depersonalization was seen in 6 patients (14%). Presentation could be truly defined as incidental in 4 instances only (8%) and a scalp swelling was seen in one case.

Cases of neurologic deficits in motor, sensory, posterior fossa signs, speech, gait and cognitive abnormalities were grouped together along with progressive visual deterioration among the orbital signs / symptoms as Non hemorrhagic neurologic deficits (hereafter referred to as NHND) and attributed as an "aggressive presentation" and tallied a total of 15 presentations (30%).

In all 33 presentations out of 49 had multiple complaints falling into the multiple of these domains (These were exclusive of 15 patients that bled, their post hemorrhagic manifestations were not credited into any other groups). For ascribing severity of presentation into aggressive, intermediate severity or non aggressive groups only the most severe presenting complaint was taken into consideration as it was obvious that the most severe clinical condition decided the prognosis and further course of management.

CLINICAL SYMPTOMS	HEADACHE	VISUAL/ ORBITAL	HEMORRHAGE	NHND	TINNITUS	SEIZURES	INCIDENTAL
Castilla	27 (51%)	4 (7.5%)	7 (13%)		27 (51%)	4 (7.5%)	4 (7.5%)
Chandra	10 (25%)		13 (33%)		14 (35%)	2 (5%)	
Hu	11 (17%)	2 (4%)	14 (22%)	7 (14%)	22 (44%)	3 (5%)	
Current study	20 (41%)	19 (39%)	15 (31%)	15 (30%)	14 (29%)	8 (17%)	4 (8%)

Our patient cohort had presenting complaints similar to those in 3 recently published series of transarterial Onyx embolisation of DAVF. Differences in incidence of symptoms in various study groups in the NHND, orbital /visual subgroups may be

attributed to varying definitions of what contributes as an NHND or differences in inclusion of Cranial nerve palsy, progressive visual loss and seizures into various sub classifications. Our rate of NHND is higher as we chose to include progressive visual deterioration as an aggressive sign separate and apart from other visual impediments. Thus overall there were 15 (30%) cases of hemorrhage, 15(30%) of NHND, together giving an incidence of 60% aggressive presentation in our cohort. On the other hand, intermediate presentations were 16% and Nonaggressive presentations consisted of 22% of the lot. Our series had less number of cases with benign symptoms like pulsatile tinnitus or orbital/ visual symptoms unlike previously described natural history or clinical series largely because of two reasons, for one - ours is a treatment cohort (Only lesions that were deemed as severe enough to mandate treatment were considered) and secondly we have excluded Cavernous region DAVFs which have a propensity to present with orbital and otologic symptoms by virtue of their topographic location. On the other hand our rates of aggressive presentations are similar to previous natural history studies that have specifically looked at incidence of clinical events in aggressive subset of DAVFs.

S.No	SERIES	YEAR	TOTAL	BORDEN 2 & 3	H	NHND	%(NHND+H) TOTAL COHORT	%(NHND+H) AGGRESSIVE GRADES
1	Bulters et al	2012	75	19,56	32	19	68%	68%
2	Soderman et al	2008	85	32,53	32	19	60%	60%
3	Van Dijk et al	2002	57	15,5	5	11	80%	19
4	Current study		49	26,20	15	15	65%	60

Clinical assessment of severity of presentation was also assessed by Modified Rankins Scale scoring. This scale commonly used for assessment of patients with hemorrhagic and ischemic stroke worldwide, was actually a modification by **Farell et al (73)** for use in the United Kingdom Transient ischemic attack Aspirin trial in 1980s for the original Rankin scale scoring given by **Rankin et al in 1957 (74)**. It is useful not only for initial assessment and triage of patients but also acts as a benchmark or baseline against which future improvements or deterioration of the patient can be objectively stated following conservative or interventional treatment.

MRS SCORE	CLINICAL FEATURES
0	No symptoms.
1	No significant disability despite symptoms , able to carry out all usual duties and activities.
2	Slight disability, unable to carry out all previous activities, but able to look after on own affairs without assistance.
3	Moderate disability, requiring some help , but able to walk without assistance.
4.	Moderate severe disability, unable to walk without assistance and unable to attend to own bodily needs without assistance.
5	Severe disability , bed ridden, incontinent and requiring constant nursing care and attention
6	Dead

In our series of 43 patients with 49 embolisation sessions, the largest subsets of patient presentations were at an MRS score of 2 - 37% (18 out of 49). There were no patients with MRS of 0 as two of our incidentally detected patients also complained of headache following trauma and one patient was suffering from deficits of stroke during evaluation of which DAVF was uncovered on the side of brain contra lateral to focus of ischemic insult. The MRS > 2 was seen in 15 patients -30.6% (9 patients with MRS of 3 and 6 patients with MRS of 4). None of the patients in the study had MRS \geq 5. One patient during the course of the study had presented with acute Intracranial and intraventricular hemorrhage with hydrocephalus and MRS of 5, could not be salvaged despite intensive supportive care and emergency neurointervention and expired within 4 days. The said patient was not included in any analysis and was excluded from the study.

Average time (mean standard deviation) from onset of the symptom that led to referral by angiographic diagnosis was 11.9 (14.63) months, The range was 0.25 to 60 months. It was noted that overall non aggressive presentations had a longer mean time to arrive at diagnosis 23.1 (20.6) months in comparison to aggressive 9.09 (11.04) months or intermediate severity presentations 7.2 (6.1). Among aggressive presentation subtypes, It was noted that although both haemorrhage and NHND had a median presentation of 15 months hemorrhagic presentation had a shorter mean interval to diagnosis with a smaller standard deviation - 5.3 (8.3) months in comparison to NHND 12.8 (13.8). Both these associations were noted to be statistically significant ($p = 0.012$). As the acuity of symptoms decides the referral pattern to our institute, the time period between presenting complaints and diagnosis by angiography, which is considered as an invasive modality therefore is understandably variable. A catastrophic presentation with hemorrhage, LOC or a more dramatic presentation as in seizures, rapid visual deterioration or cognitive decline may prompt patients to seek immediate medical

evaluation and possibly imaging assessment, where upon if ICH, hydrocephalus, abnormal prominent or congested appearance of intracranial vessels arise the suspicion of an underlying vascular abnormality. Such patients receive a relatively early DSA. On the other hand non aggressive presentations like, headache, tinnitus or isolated non progressive focal deficits like cranial nerve deficits tend to be not prioritized by patient themselves or primary care facilities wherein patients may receive conservative or symptomatic supportive treatment for varying periods of time.

6.1 ANGIOGRAPHIC ATTRIBUTES AND CLINICAL SEVERITY:

The following angiography the following attributes were noted :

- ❖ Number of lesions and multiplicity
- ❖ Laterality of the lesion
- ❖ Site of the lesion , venous sinus/ sinuses involved
- ❖ Arterial supply: feeders, ECA v/s ICA supply, Unilateral versus bilateral supply, anterior circulation versus posterior circulation supply, left and right sided arterial supply.
- ❖ Venous drainage : presence of Cortical venous reflux, presence of ectasia, signs of venous hypertension , dural sinus/ venous stenosis or occlusion
- ❖ Circulation time
- ❖ Classification schema: Embryologic classification, Borden Schucart System, Cognard system, Directness, Exclusivity and Strain pattern.

1. Number of lesions: A total of 75 lesions were identified in 43 patients presenting in 49 embolisation sessions. Lesions presenting denovo on subsequent angiograms were counted as separate lesions. There was no duplication of lesions when same patient underwent subsequent embolisation sessions. In 29 /49 (59%) instances there was only a single lesion, which was treated. In 11 instances (22%) there were 2 lesions, in 4 instances (8%) 3lesions were identified, in 2 cases (4%) 4 lesions were seen and 6 lesions were identified in 3 (6%) instances. Thus multiplicities of lesions were identified in 41% of our study population. **Van Dijk et al** in 2002 (39)in their consecutive series of 284 patients with DAVF in the Toronto experience had a given an incidence of multiplicity of about 8% with almost 63 % of their subgroups with multiple fistula showing 2 lesions. They also identified higher incidence of CVR in such patients, which by current knowledge is a clear indicator of hemorrhagic presentation. Since our patient group was not a continuous series and included only the patients that were deemed to be treated due to the aggressive nature of fistula, the higher proportion of multiplicity could be explained. Multiplicity may also be increased because of presence of DM in 20% of our patient group as previously explained. However in our group CVR was present in all but one patient each in the single as well as multi site fistula subgroup, unlike the van Dijk study. It may be because it consisted of only treated patients and if they had no CVR they would not have been treated in the first place.

Of the 15 patients that presented with NHND 10 (67%) had multiple lesions and 5 (33%) had single lesions. Of the 15 patients that bled this ratio was reversed with 33% having multiple lesions and 67 % showing singular lesions only. Intermediate presentations showed an equal number of instances with single and multiple lesions. In non aggressive presentations there was a much higher incidence of 73% of singular lesions compared to multiple lesions (27%). No significant statistical difference could be

demonstrated between clinical presentation subtypes and multiplicity of the lesions ($p = 0.16$). When aggressiveness of presentation was considered by pooling H and NHND statistical association became further weak ($p = 0.41$).

2. Laterality of the lesion: DAVF may occur in relation to a midline dural sinus or venous structure like SSS or Straight sinus or it may occur in relation to lateral dural structure like the paired veins or dural structures. They are also now known to occur in relation to cortical and bridging veins and also emissary veins, in which case they may be lateralized. Common sites of DAVF like Transverse and sigmoid sinuses are known to occur more on the left side (75, 76). In our study lesions were sometimes seen extending on either side in addition to midline. In our study the lesions involved right side in 26 instances and left side in 21 instances. In 19 instances it was seen to involve the midline. In 14 cases of DAVF engaging the cortical vein it was attributed to the corresponding hemisphere. It was noted that presence of shunt on either the right or left side was not statistically associated with any specific presentation or aggressive or non aggressive nature of disease. However it was noted that 11/15 (73%) NHND patients had presence of fistula in the midline and 13/15 (87%) of H patients had a laterally placed fistula and that this association was statistically significant (P value = 0.007). However when the aggressiveness of presentation (by pooling H and NHND) was interrogated in the light of laterality of lesion the H and NHND patients diluted the significance mutually and no statistically significant association was noted between laterality versus midline presentation on aggressive versus non aggressive presentation. Such association has not been previously reported in literature. It is known fact that the dural venous system of the brain drains the cortical surface preferentially via one side Transverse sinus and the deep venous system via the opposite side. A fistula on midline location such as torcula may simultaneously congest both systems and produce venous hypertension in cortical and

deep parenchyma in addition to affecting both cerebral hemispheres instead of one like a laterally placed shunt would promoting congestive changes in larger volumes of brain parenchyma producing functional overwhelming of parenchyma with signs of global neurologic deficits. On the other hand a laterally placed shunt has limited outflow facilities in comparison to a midline shunt and in due course of time in the face of progressive compromise of existing outflows they may tend to present more with haemorrhage which is more of a model of physical decompensation than functional compromise.

3. Site of the lesion: As previously mentioned the topography of the lesion has a large say in presentation, natural history, treatment strategy, outcomes and ultimately prognosis of the patients. In our study there was a heterogeneous mixture of lesions involving superficial cortical dural sinuses from SSS to IJV, deeper dural sinuses like tentorial sinuses, bridging and cortical veins. Of the 75 lesions identified most common locations were the TS and convexity veins with 15 lesions (20% each). Lesions' involving lateral most aspect of TS was considered as a TS lesion and not a TS-SS junction lesion. Lesions involving relatively equal parts of TS and SS including the TS - SS junctions were considered as TS -SS junction lesions. Next common location were SSS and torcula with 10 (13%) and 9 (12%) lesions respectively. there were 4 TS-SS junction lesions, 1 torcula -TS lesion, 1 SS , 2 SS- IJV lesions and 5 lesions of IJV. There were three extensive fistula involving torcula-TS-SS and IJV. There were 2 Middle cranial fossa lesions and 6 tentorial lesions. (tentorial shunts involved marginal tentorial shunts located along the Superior petrosal sinus -4 , lateral tentorial shunts adjacent to lateral venous sinus -3 and medial marginal shunts involving the straight sinus and adjacent regions of falco- tentorial junction -1).

For convenience in comparative assessment and to make meaningful inferences, in accordance to **Geibprasert et al (29)** the 49 treated lesions were classified as Dorsal epidural (osteo membranous) fistula (From SSS to TS-SS junction), Ventral (osteo cartillaginous) epidural fistula (SS- IJV) and lateral epidural (involving the tentorial and middle cranial fossa shunts). DAVFs engaging the cortical and bridging veins were classified separately as they were clearly having a radically different presentation and natural history when compared to the sinusal shunts. Thus most of the lesions 24 (49%) treated were topographically located along the SSS to TS-SS junction (Sinusal dorsal epidural shunts), Next most commonly treated locations were the bridging and cortical venous shunts (Extrasinusal dorsal shunts)14 (29%). There were 2 trans spatial fistula involving both dorsal and ventral dural sinuses to relatively similar extent. 3 (6%) shunts were treated in the SS-IJV region (Ventral epidural shunts). One MCF shunt and 5 (10%) tentorial shunts were treated.

The relative topographic incidences of lesions reported are:

- 1) Transverse sinus Most common (38%)
- 2) Cavernous sinus -35%,
- 3) Tentorial 5%,
- 4) Anterior cranial fossa -5% [**Malek et al] (77)**
- 5) SSS -5% [**Awad et al (5)**]

Our results are comparable to general results in case of some locations while discordant from yet others like Cavernous sinus and ACF locations. This is in part because we excluded Cavernous sinus shunts from this study as they have by and

large a benign natural history with large numbers [up to 73% (78)] undergoing spontaneous thrombosis without active intervention. We did not have any case of Anterior cranial fossa fistulas which may be a chance event as it is rare location for fistula. We also have categorized some of the bridging venous fistula close to dural sinuses as convexity bridging vein fistulas and not fistulas of corresponding dural sinuses according to **Baltasavias et al** in 2015 (33).

Series	Year	TS (%)	CS (%)	Tentorial (%)	ACF (%)	SSS (%)	MCF	IJV	Convexity
Mc Dougall	1997	38	35	5	5				
Castilla	2014	40		9.5		3.2	3.2	9.6	7.9
Current series (75)		31	-	9.3	-	13.3	2.7	10.7	20%

4. **Arterial supply:** Arterial supply to dural fistulas typically arises from Dural branches of ECA like the meningeal arteries and also dural branches of ICA and VAs. Branches from Occipital arteries (OA), ascending pharyngeal arteries (APA) and cervical arteries are occasionally found. In our study in 43 patients presenting with a total of 75 fistulae, 288 separate arterial feeders could be identified in total. 68 (65 MMAs and 3AMAs) meningeal feeders from ECA were identified which was the most common arterial supply (91 %). It was closely followed by transosseous feeders from occipital arteries. Other branches from ECA included STA and APA which were seen in 11 and 17 instances and anterior deep temporal artery in one case. Dural branches from Vertebral arteries and ICA were identified 43 & 32 times respectively. Dural branch of PCA was the only feeder in a tentorial fistula in one case. Ophthalmic artery was

identified as a feeder in 13 cases chiefly through its anterior falcine branch. Ascending and deep cervical branches of subclavian arteries were seen feeding the fistula in 4 cases. In addition pial branches from ACA, PCA and MCA were seen in 2, 16 and 14 cases respectively. Feeders from Anterior inferior cerebellar arteries (AICA) were identified in 2 cases.

Arterial feeders to a lesion typically depend on its topography. In most cases the primary feeders may be the dural branches vascularizing the meninges, with subsequent recruitment of adjacent arterial supply to integumentary tissues, calvarium or brain. The presence of multiple feeders converging to a single fistulous point was the greatest impediment to conventional trans arterial treatment, as it required separate catheterization of individual feeders and selectively embolizing each and every pedicle, making it a tedious, difficult and often unsuccessful procedure despite the associated expenses in resources, time, contrast dose and radiation penalty. The ability to reflux onyx into multiple converging feeders following a single pedicle injection has been a major breakthrough in this regard. However it still makes intuitive sense that the lesser number and type of feeders a lesion possesses the more it lends itself to effective transarterial endovascular treatment. We analyzed the arterial supply of the lesion from its various subtypes and multiplicity of arterial feeders as unilateral v/s bilateral, Right versus left, supply from one side versus sides, ECA v/s ICA supply and anterior circulation v/s posterior circulation.

In our current study there were 49 embolisation sessions we encountered in 90% of cases lesions with vascular supply from both ECA and ICA. In 8% of instances the supply was only from ECA whereas in 2 % cases it was only from ICA. 61 % of lesions had unilateral supply whereas 39 % of lesions had bilateral arterial supply. 15

(30.6%) lesions had arterial supply from left and 15 (30.6%) lesions from right side. A majority of the lesions 19 (39%) however had supply from both sides. 33 % of lesions had exclusive supply from the anterior circulation and only 2% had exclusive supply from posterior circulation. Again a majority of lesions 65.3% recruited supply from anterior as well as posterior circulation. There was however no significant statistically significant association between any of these patterns of arterial flow recruitment and aggressiveness of clinical presentation or any specific subtype of presentation. When these specific patterns of arterial supply were cross tabulated against angiographic characteristics like Borden, Cognard, DES and embryologic classification schema, presence of CVR, venous hypertension, venous ectasia and circulation time, statistically significant associations were noted only between " anterior / posterior/ combined' arterial supply and Borden (p values = 0.006) & Cognard grades (p value 0.002). 12 /16 (75%) anterior alone supply lesions belonged to Borden grade 3 (3/16 Borden 2 and 1/16 Borden 1 lesions). On the other hand 23/32 (72 %) of the lesions with combined anterior and posterior circulation tended to be type 2 Borden lesions (7/32 Borden 3 and 3 /32 Borden 1 lesions). 10 /16 (63%) lesions with anterior supply belonged to Cognard types 3 & 4. Similar to Borden, 23/32 lesions with anterior and posterior supply belonged to type 2A+B. This association is **chiefly due to topography of the lesion** with all Borden 3 (Type 3 &4 Cognard) were cortical venous shunts (recruited anterior supply alone in 64% of instances) and 20/24 (83 %) of Type 2 Borden Type 2 lesions were along the SSS to TS -SS junction Dural sinuses (anterior as well as posterior circulation in 83% of instances).

The similarity in these two situations arises because of the similarity in grading used in both systems (Type 3 and 4 Cognard corresponding to type 3 Borden. Type 2 Borden is similarly corresponding to Type 1 to Type 2 A + B of Cognard). The

small absolute difference is due to the definition of 4 isolated dural sinus lesion which is ascribed grade 3 in Borden whereas corresponding Cognard class has not been defined in the original scheme and therefore was ascribed Cognard Type 2 A+B in this study).

5. **Venous drainage:** Venous drainage patterns of lesions were analyzed for presence of Cortical venous reflux, presence of ectasia, signs of venous hypertension, dural sinus/venous stenosis or occlusion and circulation time. CVR was most commonly seen venous characteristic (96% of treated lesions). Signs of venous hypertension were seen in 74% of patients. Circulation time was less than or equal to 7 seconds in 26/49 instances (53%) and it was prolonged more than 7 seconds in 23 instances (47%). Circulation time was measured from serial angiographic runs as the time elapsing after appearance of contrast in cavernous ICA or basilar artery and the very first appearance of contrast in non shunting parietal or posterior fossa cortical vein. The time interval was calculated indirectly by dividing the number of frames between these two events occurring by the frame rate of acquisition. Dural sinus or draining vein stenosis or occlusion was seen in 80% of cases. Venous ectasia were seen in 26.5% of cases that is in 13 instances. Ectasia were defined as a focal venous dilatation more than thrice the diameter of the preceding normal segment or more than 5mm in diameter. Ectasia were seen in 7 type 4 lesions and 4 type 2 A+B (on refluxing cortical veins), 1 type 2 B, and one type 3 lesion wherein ectasia was on a secondary draining vein and not primarily on the cortical vein receiving shunt flow.

7. **Cases of ectasiae:** (3 type 2A+B, 4 type 4) were in instances with hemorrhage (6/15 - 46% of instances with hemorrhage) .Ectasia were notice on 6/34 instances without hemorrhagic presentation (17.5%). This association could not be demonstrated as a

statistically significant one ($p = 0.141$) despite the known risk factor of hemorrhage introduced into natural history of the disease by presence of ectasia (79). This may be due to relatively small size of this study which is primarily a treatment cohort.

The presence of Venous ectasia also did not show any significant association with demographic variables like age, sex or duration of complaints. It also did not show any significant association with other angiographic characteristics like presence of CVR, venous hypertension, dural/ venous sinus compromise or circulation time. However it did show a statistically significant association with the topography of the lesions ($p = 0.042$) in that it was present in 4 out of 5 tentorial fistula treated (80%) but only in 5/14 (36%) cortical/ bridging venous fistulas and 3/24 (12.5 %) of SSS to TS-SS junction fistulas. Again this can be attributed to the topography of the lesion location in the tentorial region where prominent dural or venous outflows are not available to decompress the shunt and smaller veins servicing the shunt rapidly deteriorates into a model of physical decompensation with development of ectasia in the face of systemic arterial pressure. This situation is not seen usually in sinusal or venous shunts elsewhere due to availability of more capacious venous shunts or alternative outflows.

6.2 Classification schemes:

A. ***Borden Schucart classification***: Of the 75 lesions present there were 10 type 1 , 50 type 2 and 15 type 3 fistula. For this scheme of classification in 49 treatment instances, the most severe grade of fistula at a given instance was taken into consideration when there was more than one fistula at a time. Isolated segment of dural sinus was seen in 4 cases and was included as Borden type 3 lesions.

	<i>B1</i>	<i>B2</i>	<i>B3</i>
Current study (49 instances)	3(6%)	26(53%)	20 (41%)
Chandra et al (41 lesions)	8(15%)	7(22%)	26 (63%)
Natarajan et al (32 patients)	6(19%)	13(40.5)	13 (40.5)

In our series the 3 Borden 1 lesions presented with non aggressive clinical features whereas out of 26 Borden 2 lesions 11 presented with NHND and 7 presented with H (overall 18/26 -69% aggressive presentation in comparison to 31 % intermediate and non aggressive presentations). Out of 20 Borden type 3 lesions 8 had H and 4 had NHND (12/ 20 -60% had aggressive presentation and rest of 40% had non aggressive or intermediate severity presentation). This association was statistically significant ($p = 0.032$ for Borden versus H/NHND/I/NA and $p= 0.022$ for aggressive vs. intermediate/ Non aggressive clinical presentations). Our results are in agreement with the original descriptions and clinical correlations given by Borden et al (30).

B. Cognard's Classification: In 75 lesions identified there were 5 Type 1 lesions, 6 Type 2A lesions, 12 Type 2B lesions, 36 Type 2 A+B lesions, 10 Type 3 lesions and 6 Type 4 lesions. There is no specific typing mentioned for isolated sinus shunts (ISS) unlike the Borden grading in the Cognard's system. Since such shunts severity would be expected to be more than a 2B (anterograde sinus flow with CVR) and less than a Type 3(A direct cortical venous shunt), ISS were placed for the purpose of this study along with the Type

2 A +B shunts, although a case may be made that these may be a more aggressive subtype of Type 2 A+B shunts. As in the case of Borden Classification, for this study of 49 treatment instances - the shunt with highest severity grade according were chosen. The most common type was Type 2A+B, seen 26 (53%) of instances and the least common was the Type 1 which was seen in one case (2%). We did not encounter any lesion that had direct spinal perimedullary reflux; therefore not defined any Type 5 lesions. There were instances of secondary perimedullary reflux identified in 2 lesions but the Cognard classification does not clearly specify if reflux into perimedullary reflux indirectly classifies as a type 5shunt, therefore in this study the said shunts were placed in Type 3 category as the primary receptacle of the shunt was a bridging vein in the falco tentorial junction. 82% of our treated lesions were Type 2 A+B or more severe, as we intended to treat only the most severe lesions with CVR unless of course was otherwise indicated. When Cognard classification was cross examined with clinical presentation and severity of presentation it was found that 4/4 (100%) type 1 and type 2A lesions presented with NA or intermediate severity but 3/4 (75%) of type 2B lesions presented with NHND and 18 /26 69 % of type 2 A+B presented aggressively. Likewise, 5/8 (62%) of type 3 lesions and 4/7 (57%) of type 4 lesions presented aggressively. As in the Borden system severe grades generally presented with more aggressive presentations and milder grades tended to have more of non aggressive to intermediate clinical presentation, however unlike the Borden system a significant statistical association could not be demonstrated (p value - 0.081). This may be due to the fact that Borden has 3 grades as against Cognard which has 7 grades leading to further reduction of numbers in each subtypes weakening the statistical association.

Series	Number	Type 1	Type 2A	Type 2B	Type 2A+B	Type 3	Type 4	Type 5
Current study	49	1(2%)	3(6%)	4(8%)	26(53%)	8(16%)	7(14%)	0
Castilla	63	22(35%)	→	→	→total 8(13)	21(33%)	9(14%)	3(4.5%)
Chandra	41	5(12)	3(7)	3(7)	4(10)	15(37%)	11 (27%)	0

C. **DES classification**: For the directness, exclusivity and presence of venous strain classification of shunts with CVR we made two sets of classifications. The first one was DES clinical severity in which the most severe grade of fistula (in patients with multiple lesions) according to DES classification was tabulated. The second one was DES Rx in which we assigned DES severity grade to the lesion being treated at that sitting. This was done because in some patients with multisite lesions, at times it so happened that the lesion with most DES severity was not the one that was treated. Treatment decisions were taken at that time based on clinical situation at hand.

Series	No. CVR	nDnEnS	nDnES	nDnES	nDES	DnEnS	DnES	DnES	DES
Current 1	3(6%)	8(16%)	14(28.6%)	0	5(10%)	0	8(16%)	1(2%)	10(20%)
Current 2	3(6%)	5(10%)	14(28.6%)	0	4(8%)	2(4%)	7 (14%)	4(8%)	10(20%)
Baltasavias	0	23(21.5%)	9(8.5%)	7(6.5%)	11(10%)	2(1.9%)	2(1.9%)	16(15%)	37(34.5%)

In this study the separate sub categories of DES classification did not yield any significant statistical associations with demographic parameters like age, sex, clinical

presentation, aggressiveness, duration of illness, comorbid conditions or angiographic parameters like lesion location, multiplicity, arterial supply, venous drainage circulation time. This was expected as 8 sub classification of our 49 subjects yielded very few numbers in each class to be statistically useful. Hence we attempted to re classify presentation as aggressive (H+NHND) and non aggressive (intermediate + benign) and further examine the significance against each of the DES attribute that is Directness, Exclusivity and presence of venous strain in a binary yes - no format. 3 patients without CVR were excluded from analysis.

For directness -15/23 (65%) direct and 14/22(64%) non direct shunts presented aggressively (p value 0.757). For exclusivity 12/18 (67%) exclusive and 18/28 (64%) nonexclusive shunts presented aggressively (p value- 0.563). For Strain 22/35 (63%) strain + and 8/11 (72%) non strain shunts presented aggressively (p value 0.415). Thus there were no statistical associations that could be demonstrated unlike Baltasvias et al where in all three attributes showed significant statistical association with aggressive VS non aggressive presentation (p value -0.0001). This may be due in part to less number of patients (original article had more than twice the number of our subjects) or due to a wrong interpretation and application of this relatively new classification from our part.

D. **Embryologic classification:** The embryologic classification was done according to Geibprasert et al (29). In this study the most aggressive fistula by Borden grade at presentation was considered in case of multiple fistula and when there were more than one fistula with same grade, the treated lesion was considered. The most commonly encountered type was dorsal epidural type 37/49 (75%). Ventral epidural was seen in 3 (6%) of cases and lateral epidural was seen in 5 (10%) of cases. 2 cases of extensive trans spatial fistula were seen in 4 (8.2%) cases and were considered as DE+VE lesions.

Series	Total	DE	VE	LE	DE+VE
Current series	49	37(75%)	3(6%)	5(10%)	4(8.2%)
Geibprasert	300	67(22%)	150(50%)	63(21%)	0

The embryology based stratification of cases were analyzed for association with demographic variables like age, sex, clinical presentation and aggressiveness and lesion related angiographic attributes like multiplicity, CVR and presence of out flow restrictions. It was seen that large majority of all groups of lesions belonged to 4th to 6th decade - 33/37 (89%) of DE, 2/3 (67%) of VE, 3/5 (60%) of LE and 3/4 (75%) of DE+VE had age group between 30 to 60 years. There were 2/37 patients of 0-30 age group in DE group, 1/3 in VE, 1/5 in LE and 1/4 in DE + VE group. No significant associations were noted ($p=0.38$). The VE and DE +VE group had the lowest mean ages (38.7 and 38.3 respectively), whereas the LE group had highest men age 49.2. In the original study the lowest age group mean was seen in the dorsal and highest mean was seen in LE subgroups which was statistically significant ($p < 0.001$). However there was no statistical significance ($p=0.425$) unlike Geibprasert et al in our series

AGE	DE	VE	LE	DE+VE
Current study	43.7(9.3)	38.7(12)	49.2(21.16)	38.3(8,77)
Geibprasert	28	51	56	-

The male to female ratio in DE was 30: 7, in VE was 1:2 , in LE was 5: 0 and DE+VE was 3:1. There was a male predominance in DE & DE+VE and female predominance in VE(67%). LE was found exclusively in men (100%). However none of the associations were statistically relevant. In Geibprasert study VE lesions showed predominance in female patients (70%) and LE patients showed strong male predominance (81%)(Similar to our study however both of which were statistically significant as well, with p values <0.001 in each case) with no obvious sex predominance in DE lesions (41:46) unlike our study which was showing a male predominance(81%). Clinical presentation wise 62% (23/37) of DE fistula and (3/5) 60% of LE showed aggressive presentation whereas only 1/3 (33%) VE fistulas were aggressive in presentation. The DE+ VE subgroup also showed aggressive presentation in 3/4 (75%) of cases. None of these associations reached any statistical significance in our study. In contradistinction the large majority of VE fistula in Geibprasert group were non aggressive in presentation (92%) whereas majority of patients of LE Subtype had aggressive presentation (86%) ($p < 0.001$). Their DE group also had a tendency to present more with aggressive symptoms but without strong statistical backing unlike the other two subgroups.

In our series DE lesions were multiple in 20/37 instances (54%), VE in 0/3 (0%), LE in 1/4 (25%) cases DE +VE in 1/3 (33% of cases). Again this association did not reach statistical significance ($p = 0.133$). In Geibprasert study highest rate of multiplicity like in our study was associated with DE fistula -36% and lowest in LE fistulas -9%. VE showed 12 % multiplicity in their series and all three were statistically significant associations with ($p < 0.001$).

In our series CVR was present in most of the cases (presence of CVR being the strongest advocate for treatment and therefore inclusion in this study). It was seen in 36/37 (97%) of DE 2/3 (67%) of VE and 100% of DE+VE and LE ($p=0.068$ - not significant). Geibprasert et al showed CVR presence in 100% of LE , 81 % of DE + VE, 65% of DE and only 30%VE (This differential presence of CVR among all the single type shunts DE, VE & LE were significant statistically- $p < 0.001$).

In our study out flow restrictions were seen in 31/37(84%) of DE, 2/3 (67%) of VE, 1/4 (25%) of LE and 100% of DE +VE(However statistical significance was not reached for this association, $p = 0.087$). In their study Geibprasert et al noted a 90% incidence of outflow restrictions in DE, 75% incidence in VE and only 17 % in LE. These figures are similar to our experience, however they were able to demonstrate statistically significant differences between their different groups ($p<0.001$).

The differences were largely because the original study was a larger group of 300 consecutive cases of both cranial and spinal dural fistulas across all age groups and all locations in brain and spine. Their final analysis also excluded all multisite fistulas. Ours population by comparison was smaller consisting of only adult type of Cranial DAVFs which were all aggressive cases requiring treatment with a multiplicity rate of 45% overall. We had excluded pediatric cases and Cavernous sinus region fistulas from the said analysis but have retained multisite fistulas as they formed a significant part of our group. The pediatric cases as well as Cavernous indirect fistulae have different etiology, clinical features, natural history and prognostic significance with associated treatment implications and we chose to leave them out of this analysis at the time of study design itself. Therefore our study could not be powered sufficiently to demonstrate statistical significance of the observations in parallel to those of Geibprasert et al.

6.3 TREATMENT

In 43 patients a total of 75 DAVFs were identified. 49 transarterial Onyx embolisation sessions were undertaken for 49 lesions. 6 of these lesions required subsequent onyx embolisation sessions, 4/6 of these were due to incomplete or failed procedure at the first instance. In the other 2 cases repeat embolisation was planned after recurrence was demonstrated at DSA following prior seemingly successful occlusion. 4 out of these 6 procedures resulted in complete cure at the second attempt while 2 others continued to have poor result despite the second attempt. None of the patients underwent subsequent surgical or radiosurgical management of the lesions.

For this study we have considered only trans arterial endovascular embolisation with Onyx alone or primarily with Onyx along with supplementary alternative embolic agents. 7 patients feature twice in 49 embolisation sessions. For 6 of these instances embolisation were performed at different times. In one patient two lesions on either side of head were embolized sequentially one after the other through two separate arterial Pedicles (R & L MMA) as the situation demanded immediate disconnection of fistulous communication as soon as possible. In three patients there were worsening of complaints following initial unsuccessful treatment (in one patient there was intermediate severity presentation initially which presented with NHND subsequently, second patient presented with different NHND on each of the occasions, the third presented with hemorrhage first time and NHND subsequently). In two cases there were fresh symptoms after successful initial embolisation attributable at DSA to a fresh lesion which was subsequently treated (one patient presented with intermediate symptom initially and subsequently with NHND and the second one presented with NHND first time and intermediate severity presentation subsequently). In one patient with two aggressive lesions on either side was treated sequentially one after the other

on two separate occasions one month apart (at both instances he only complained of non aggressive symptoms).

In 49 transarterial onyx sessions, 57 arterial pedicle onyx injections were done. MMA was most commonly injected followed by OA (**49 MMA injections**, 6 OA, 1 ApA, 1 dural BRANCH OF PCA). In all there were 42 cases (85.7%) of complete to near total occlusion and 7 cases (14%) of failed or incomplete occlusion. Follow up DSA was available in 30 instances - 57% (25 with complete occlusion and in 5 case of failed embolisation). Residual lesions were demonstrated at follow up DSA in all 5 failed cases and 2 cases (4% recurrence) that were successfully embolized previously. Clinical follow up was available in every case.

Angiographic result immediately post procedure was defined as binary outcome of total/near total occlusion versus failed or incomplete occlusion. Near total occlusions were the result of minimal if any supply from arteries supplying eloquent brain structures like ApA, pial branches of ACA, MCA and PCA which at the time of embolisation was not aggressively pursued for fear of inciting neurologic deficit and was expected to thrombose in due course of time. The angiographic outcome was cross tabulated with demographic variables, angiographic attributes and specific procedural details (treatment variables) and results analyzed to find out any pointers towards a better angiographic out come.

6.4 DEMOGRAPHIC VARIABLES

1. **Age:** All the failed cases 7/7 occurred in the 31-60 years age group. All cases in the 0-30 age group (5/5) and 61-90 age group (3/3) were successfully embolised (p - 0.513). Average age of successfully treated cases was 43.98 (11.59 y) and those of incomplete cases were 40.71 (5.88).the differences were not statistically significant (p-0.270).

2. **Sex:** All incomplete embolisation were noted in males. Only 82 % of embolisation sessions were successful. All females were successfully treated. (p- 0.179) Statistical significance was not noted.

3. **Clinical presentation:** When complete versus partial angiographic results were analyzed against types of clinical presentations, it was noted that 6/7 failures (85%) was seen in the NHND group. The remaining one and only 1/7 (15%) failure was seen in H group. Only 9/15 (60%) instances of NHND were successfully treated, whereas 14/15 (93 %) of H instances and 100% each of intermediate (8/8) and non aggressive instances (11/11) were successfully embolized. This difference was statistically significant (p= 0.007). However, when NHND and H were pooled together as aggressive presentations although all 7/7 failures occurred in the aggressive presentation group and all 8/8 of intermediate and 11/ 11 of non aggressive were successfully treated. The Statistical significance was lost (p- 0.075). This may suggest that H and NHND categories may have mutually diluted their individual effects hinting at the probability that these two clinical presentations may be manifestations of same disease acting via different set of pathomechanisms with an inherent implication on treatment by transarterial onyx embolisation. Clinical severity assessed by initial MRS scale also did not show any trend or any significant association with angiographic outcome. The outcome variable was also not significant influenced by presence or absence of co morbid illness namely diabetes mellitus and cortical/ dural venous sinus thrombosis.

Successfully treated cases had a mean duration of presentation lesser than those that were incompletely treated. Mean duration of presentation in Successful cases is 11.09 (14.21) months in comparison to failed cases that had a mean duration of 17(17.38) months. (p=0.42 not significant).

6.5 ANGIOGRAPHIC VARIABLES

1. **Sidedness versus midline:** 5/26 (19%) of treatments failed when the lesion was present on the right side, whereas only 2/21 (9.5 %) failed when lesion was not present on right side. ($p= 0.263$ non significant). 3/21 (14%) of treatments failed when lesion was present on left side and another 14 % (4/28) of treatments failed when lesion was present on left side ($p= 0.663$ non significant).

It was noted that when lesion was present in the midline, 5/19 (26%) treatments failed whereas only 2/30 (6.7 %) failed when lesion was not identified in the midline ($p= 0.069$, borderline significance). However this marginal significance is to be interpreted in view of the previous statistically significant association between midline presentation and NHND as well as the association between NHND presentation and poor angiographic outcome.

2. **Multiplicity:** Out of 22 multisite fistulae treated 16 (73%) were successful and 6 (27%) failed. On the other hand 26/27 (96.3%) single site fistulae were successfully treated and only 1 (3.7%) failed. This difference was noted to be statistically significant ($p=0.025$).

3. **Site of treated fistula:** The most number of failed cases were seen in SSS to TS-SS jn- 4/24(16.7%) failed 2/14 (14.3%) of fistula of cortical and bridging veins failed the treatment. 100% of MCF, Tentorial and SS-IJV lesions were successfully treated. There was no statistical association noted for this differences however ($p= 0.594$).

49 INSTANCES	SSS TO TS-SS Jn	SS- IJV	TRANSSPATIAL	MCF	CORTICAL VEINS	TENTORIAL
TOTAL / NEAR TOTAL	20	3	1	1	12	5
INCOMPLETE	4	0	1	0	2	0

4. Arterial supply: It was noted that 4/4 cases with ECA only & and 1/1 cases ICA supply only were successfully treated. All 7 cases of failure occurred in ECA+ ICA supply group representing 7/37 (19%) of this group. This association was not statistically significant (0.629). It was also observed that, in lesions with unilateral arterial supply there was a failure rate of 4/30 (13%) and in lesions with bilateral supply the failure rate was 3/19(16%). This difference was not a significant one. It was seen that the failure rate was minimum if the lesion was present on left side (1/15) 6.7% and maximum if it was on the right side 3/15(20%). Failure rate was in between 3/19 (15.8) for lesions presenting in the midline without a laterality. This association was also not statistically significant ($p = 0.564$). It is a well known fact that right side dural sinuses are more commonly the more prominent in most people and the left side is the more common site of the two sides for DAVFs affecting TS to SS region (which incidentally is the most common location of DAVFs in most studies dealing with this subject). **Caragine** et al (80) has proposed that the higher pressures may be generated on the left side if shunt lesion is present here leading to opening up of parallel collateral channels in this region. It remains to be seen if such topographic differences and side predilection has any obvious implication for the current treatment modality under study. When arterial supply from anterior and posterior circulation was considered: 5/7 (71%) of failures occurred in lesions with both anterior and posterior supply giving a failure rate of 5/32 (16%) in this group. On the other hand only 2 failures (29%) was seen in the group with supply from anterior circulation alone giving a failure rate of 12.5% in this group.

5. Circulation time: Successfully treated cases had a mean circulation time of 7.64(3.31)s which was almost same as failed cases 7.64(2.56).

6. Angiographic results - Classification wise: For this analysis in all cases the fistula treated in that instance was considered. DES classification: DES classification of the treated

lesions at each instance was used in this classification. 3 patients without CVR were left out of the analysis.

S. No	Subtype	Complete	Incomplete
0	No CVR	3	0
1	nDnEnS	7	1
2	nDnE S	13	2
3	nD EnS	0	0
4	nD E S	4	1
5	DnEnS	0	0
6	DnE S	6	2
7	D EnS	1	0
8	D E S	9	0

No significant statistical association was noted as previously ($p=0.767$) due to large number of subtypes, Hence further stratification was done individually on the basis of each of the three variables "Directness", "exclusivity " and "Strain " and further reanalyzed. Directness was noted in (16/40) 40% of completely embolised fistula and (2/6) 33% of incompletely embolized lesions ($p= 0.56$). For exclusivity attribute it was found in 14/40(35%)

of successfully embolized lesions and 1/6 (1.7%) of failures (not significant , $p = 0.351$). Strain was present in 32/40 (80%) of completely treated lesions and 5/6 (83 %) of lesions that failed treatment ($p=0.667$).

- ✓ **Embryologic classification:** 6/7 failures (86%) were seen in DE subgroup giving a failure rate of 6/37(16%) in it. 1/7 failure (14%) were seen in the DE+ VE group which however showed a higher failure rate at 25% (1/4) of instances. All case of VE and LE were successfully embolized (p value = 0.610) - statistically insignificant.
- ✓ **Borden classification:** 5/7 cases of failure (71%) was encountered in the Borden 2 category giving a failure rate of 5/26 (19%) in this category. The rest of the 2 failure cases (29%) were seen in Borden 3 giving a failure rate of 2/20 (10%) only. However this association did not reach statistical significance ($p = 0.517$).
- ✓ **Cognard Classification:** Most failures 4/7 (57%) were seen in type 2A+B with a failure rate of 4/26 (15%). However higher rate of failure rates were seen in type 2B (1/5) 20% and Type 3 (2/8) 25%. There was no statistical significance noted (0.701). The failure incidences in Cognard types 2A+B and, 2B were equal to that of Borden type 2 and that of Cognard 3 were equal to that of Borden 3 because essentially they are the same.

7. **Venous characteristics:** 6/7 failures (85%) were seen in instances with venous hypertension giving a failure rate of 6/36(16%) in this group. On the other hand only 1/7 (15%) of failures were seen in group with no venous hypertension with a failure rate of 1/13(7.6%). These results were exactly reversed when presence of venous ectasiae were analysed. 85% of failures (6/7) was seen in instances with no venous ectasiae giving a failure rate of 6/36(16%) whereas only one failure (1/7 - 15%) was seen in instances with ectasiae giving a

failure rate of 1/13(7.6 %). However both these associations were not significant (both times p value = 0.392). All failures occurred in subgroup with outflow restrictions giving a failure rate of 18% in this group. All 10 patients in the non outflow restricting group of lesions were successfully treated.

6.6 TREATMENT VARIABLES

1: **Onyx:** Successfully treated lesions consumed more volume of onyx in comparison to failed cases. The mean volume of onyx injected was 3.27(2.97) cc in comparison to 1.73 (1.48) cc of onyx consumed per lesion in failed case. This result was statistically significant (p = 0.046). Such results are expected as successful embolisation depends on refluxing Onyx into as many possible feeders as is possible following a plug formation without refluxing into the parent vessel beyond the accepted safe limit of microcatheter retrieval. Accordingly the Onyx injection time was also on an average longer in successful cases 55.88 (28.03) mts compared to 39.43(30.24) mts in failed cases. However this was not statistically significant (p value = 0.216). The time required to achieve satisfactory embolisation may be variable and requires multiple intermittent pauses for embolic injection if it permeates into an unintended pathway. Therefore a chance element of prolongation of time interval may have well been involved. Also in failed cases if the embolic injection was not percolating in the desirable manner in the initial and mid stages of embolisation, the procedure may be terminated early leading to shortening of onyx injection time making the onyx injection time difference less statistically robust.

2: **Use of supplemental embolics:** In this group Onyx was the primary embolic agent in all cases. Supplemental embolics other than Onyx was used in 7 cases and venous protection was offered in 7 other cases alongside onyx injection. In 3/7 (43%) cases of supplemental embolic usage the angiographic result was good with complete fistula cure. In the first case

detachable coils and onyx were used for treatment of symptomatic feeding artery aneurysms in MMA in a case of Type 2 A+B TS lesion, In the second 33% glue was injected from opposite side (onyx from ipsilateral MMA) MMA in case of type 3 convexity lesion. In the third case a coil was placed in the feeding artery proximal to site of embolisation to prevent reflux of onyx proximally in a case of type 3 MCF fistula. In 4/7 (57%) of cases of supplemental embolic usage was met with poor final angiographic result. In one case PVA soaked in absolute alcohol was embolized through OA in addition to MMA onyx embolisation in a case of right TS 2A lesion, In the second case PVA was injected through Right OA in case of R TS type 2 A+B lesion. In the third case Glue was injected in proximal OA to prevent reflux in case of right TS type 2 A+B lesion. In the fourth case a Scepter XC balloon was used to catheterize the OA and attempted to "pressure cook " left TS type 2 A+B lesion. In addition balloons were deployed across patent dural sinuses when they were used by normal parenchyma for drainage and deemed as non expendable. Such balloon protection was used in 7 cases (1 Type 2A + 1 type 2B + 2 Type 2A+B + 1 Type 3 + 2 type 4) and all of them were associated with good angiographic outcome (100%). Balloon protection was attempted but failed to navigate in 3 other cases (one each in SPS (Type 3), TS and Torcula (2A+B) which were successfully embolised without any technical or clinical issues.

This difference was shown as a statistically significant ($p= 0.002$) However this may be a biased result as supplemental embolics were used in those cases that were deemed to be difficult for treatment at the outset itself. Or as in the case of the 4 failed supplemental embolic group, they were used as a palliative approach as it was becoming clear that regular embolisation through MMA feeder was not succeeding as planned. When the supplemental embolics were used as an elective method prior to embolisation as in the 3 successful cases and 7 case of venous protection the outcomes were favorable.

3: Number and type of feeders embolized: In 49 sessions 57 arterial pedicle onyx injections were made which included 49 MMA injections ,6 OA, 1 ApA, 1 dural L BRANCH OF PCA. In two cases injections were made through non MMA vessels. One case of right TS type 2A+B lesion was injected exclusively through an OA which failed failed and yet another was exclusively embolised through dural branch of PCA for falcotentorial fistula was successful. MMA and OA were injected in 5 cases 3 of which failed (60%) and two were successful (40%). In 42 cases where MMA alone was embolized 39 instances were successful (93%) whereas 3 cases failed (7%).This difference was statistically significant (p value = 0.001). It is widely recognized fact that the relatively straight meningeal arteries are the most suitable vehicles for embolisation even if they are considerably smaller in caliber than most other arteries to Dural fistula like occipital arteries, ApA, Cervical or STAs. This is because they are supported by relative tough and unyielding stretch of dura along their entire course unlike skin subcutaneous tissue or brain parenchyma through which the vessels tend to follow long and squiggly course to their target fistula. It is also easier to get to the fistulous site and deposit embolic material directly into the fistula with these arteries unlike the other vessels that have to pass through the skull through tiny osseous foramina most of the time which preempts getting to the fistula site with available micro catheters.

6.7 TRANSARTERIAL ONYX EMBOLISATION BY MMA

Since it is already well known and was demonstrated in our study as well that availability of MMA as a conduit for depositing Onyx is the single most important predictor of Successful embolotherapy and also most all of the transarterial sessions in this study except two instances were conducted through MMA. We have attempted to make a comparison of various angiographic and treatment attributes of all such MMA alone embolisation to probe for any predictors of complete occlusion. First of all the two embolisation sessions first one an

unsuccessful embolisation of type 2 A+B TS fistula by OA Onyx embolisation with the assistance of glue for flow control and a successful embolisation of tentorial fistula through a dural branch of PCA were excluded. Two cases where in two MMA pedicles each were embolized for treatment in two fistula in one patient and one fistula in another case were separately analyzed as two instances each along with the rest of 45 instances. Thus there were 49 embolisation sessions through 49 MMA pedicles with 43 (87%) of them counting as successful procedures and 6 (12%) as failures. Thus it was noted that success rate has marginally increased and failure rate has marginally declined.

The angiographic outcome was analyzed as binary variable as previously mentioned (Complete / near total vs incomplete/ failed embolizations) and statistical analysis was performed by comparing means of the following attributes of transarterial Onyx embolisation through MMA pedicle.

- I. Duration of symptoms (months)
- II. The no of lesions.
- III. The circulation time.
- IV. The size of MMA feeder in mm.
- V. Volume of onyx in ml per MMA feeder
- VI. MMA onyx injection time per feeder.
- VII. The final distance of catheter tip from fistula.
- VIII. The feeder length to fistula distal to skull base
- IX. The tortousity of MMA feeder as total number of 90 degree bends

The average duration of symptoms in the successfully treated group was lesser at 10.83 (14.079) months in comparison to the patients that failed the treatment 15.83 (18.73). This difference was not statistically significant ($p= 0.44$) and appeared similar to the general cohort analyzed previously.

The mean number of lesions in the successfully treated group was 1.58(1.16) which was lesser than the mean number of lesions in the failed group -2.5 (1.38). this difference also was not statistically significant ($p=0.082$).

Circulation time was similar in both cohorts with successfully embolised group having 7.814 (3.46) similar to failed group - 7.25 (2.56).

The mean size of MMA feeder through which embolisation was performed (average of proximal diameter at skull base and distal diameter just proximal to fistula) was 1.47 (0.82) mm in completely embolised cases and it was 1.12 (0.33) mm in failed cases . This difference was not significant (0.127).

The mean volume of onyx in cc used in successfully treated lesions was higher 3.10 (2.27) than in failed cases 1.60(1.62). However the strength of this association seen previously was weakened now and was no longer statistically significant (0.080). Overall 0.3 to 15 cc, mean of 2.27(3.82)cc of Onyx was injected per patient. It may be argued that onyx volume used may not be a good surrogate marker of treatment efficiency as onyx may be expended in proximally refluxing the embolized artery, pooling or escaping via runoff into the venous side or extensively painting the radiating proximal parts of already disconnected feeders, just as much as it would take to successfully take down the fistulous point connections of multiple converging arterial channels. MMA onyx injection time was also accordingly longer 52.95 (25.93) mts in successful cases in comparison to

34.33(31.61) mts in failed cases. ($p=0.115$ non significant). Overall the time of injection varied from 2 to 130 mts with a mean of 53 (28.62) mts.

The mean distance of micro catheter tips from the fistula were 2.35 (2.64) mm in good angiographic outcome cases in comparison to 24.72 (33.73)mm in failed cases. ($p=0.65$ non significant). It is a well known fact that getting to the fistulous site with the catheter tip and deposition of the liquid embolic as close as possible to the fistulous site is the single most important predictor of a successful fistula disconnection. However in the current study the mean in the failed group was skewed towards the right by two extreme values as evidenced by the wide standard deviation in this case.

Feeder length distal to skull base was measured from angiograms on AP or lateral projections which ever was longer. The mean distance in successfully embolised cases was 107.87 (41.43) mm while it was 111.05 (32.4)mm in failed cases.

Tortousity: The tortous course of MMA was assessed in terms of the number of 90 degree bends made by the catheter within the arterial feeder that could be counted on AP and lateral images were tallied and analyzed. It is noted that when micro catheter traverses the thin meningeal vessels, it straightens out some of the curves on the vessels. The curves that still remain were counted for analysis. On AP plane the mean number of bends noted in successfully embolized feeders were lesser 4.44(1.53) in comparison to failed cases which had more number of bends in Ap plane mean -6.17(2.32) ($p =0.13$ -not significant). Likewise the feeders of successfully embolized lesion showed fewer bends on lateral plane 4.53 (1.67) in comparison to failed cases mean -7.33(2.16). Total number of bends were also seen more on failed cases 13.5(3.39) in comparison to successfully treated cases 8.98(2.82). Bends on lateral plane and total bends were statistically significant showing p values of 0.023 and 0.021 respectively.

Statistically significant variables affecting angiographic outcome, following trans arterial Onyx embolisation of DAVFs are:

VARIABLES	ATTRIBUTE	CATEGORIES	P value
Demographic	Clinical presentation	NHND/H/I/NA	0.007
Angiographic	Multiplicity	Single /multiple	0.025
Embolisation	Onyx volume in cc	Mean(std dev)	0.046
	Supplemental embolic	Used/ not used/ venous protection	0.009
	Embolized feeder	MMA/ MMA+OA / other	0.019
	Bends on lateral	Mean(std dev)	0.023
Specific to MMA	Total bends	Mean(std dev)	0.021

Ever since the introduction of Onyx for embolisation of Dural AVFs the focus of endovascular treatment has come back to the arterial side from the venous side. The biggest advantage of Onyx in this regard has been the ability to cannulate a single tiny relatively straight forward preferably meningeal arterial feeder to the malformation, form a small occlusive plug of onyx in the vicinity of the catheter tip and continue to inject the liquid embolic as it backs up against the plug into the fistula and from there refluxes back into multiple small tiny arterial feeders that converge towards the lesion. This avoids having to go into each and every one of these feeder separately with different microcatheters to achieve arteriovenous

disconnection. It thus effectively cuts down the cost and duration of procedure (largely because of the need for only single microcatheter cannulation). In addition it also reduces the risk of the procedure, as piecemeal embolizations or accidental occlusion of venous outflow prior to complete fistula disconnection are not an acceptable outcomes because of the immediate associated risk of redirection of venous drainage or hemorrhagic complications.

The ability of Onyx to percolate into multiple feeders at varying distances from the catheter tip retrogradeley against arterial pressure cannot be explained by capillary action alone. Once the initial plug forms and converts the whole fistula structure into one continuous compartment, the driving force is the pressure energy of the onyx column exiting the tip of the catheter. This pressure energy is provided primarily by the operators' thumb at the proximal end of syringe attached to hub of microcatheter containing the column of onyx. The proximal pressure is limited however by the allowable rate of injection of Onyx as well as by the absolute physical properties of the microcatheter (81). It is generally advised to keep the injection rate at less than 0.3ml /mt to maintain safe injection pressures within the catheter. Beyond the safety aspect Siekmann et al also demonstrated that increasing the injection pressure only causes more retrograde reflux without ante grade permeation. Therefore it may be deduced that pressure head of onyx column that provides pressure energy perpendicular to the walls allowing permeation into arterial branches against arterial pressure depends on the amount of loss of pressure head from the point of transmission at the proximal hub of the microcatheter to the point of its exit at distal end of microcatheter at the fistula site.

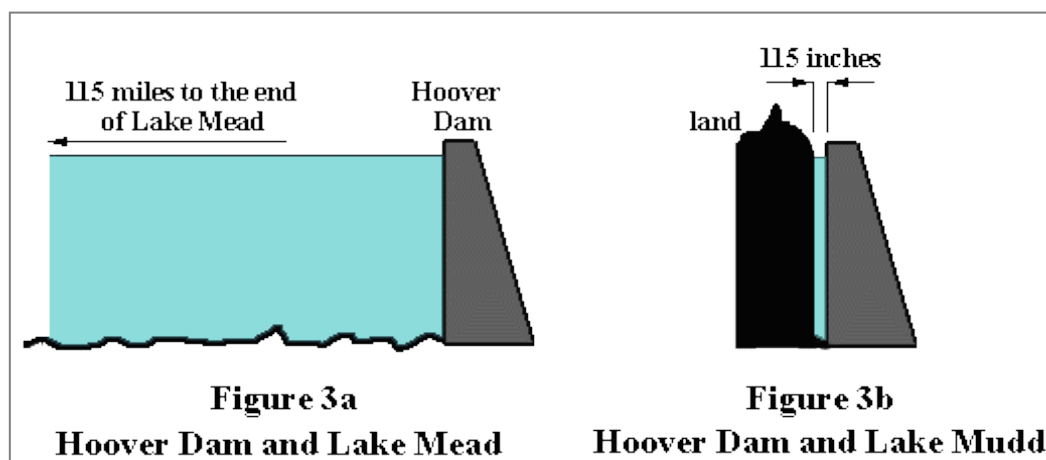
This concept may be discussed with reference to some principles of fluid dynamics taking the example of Pascal's Hydrodynamic paradox.



A liquid in an interconnected container reaches to the same height in every one of those containers and the pressure at the bottom of each part of the containers depend only on the absolute vertical height of the fluid column in the container and not the amount of fluid that it holds.

A DAVF may be likened to one of these containers wherein embolization with a liquid embolic is attempted through one of the limbs. The pressure head here is however not the vertical height of column but the pressure energy transmitted to the tip of the Catheter like in the case of a hydraulic lift. A volume of onyx exiting the microcatheter without significant pressure energy due to transmission losses might not reflux up any feeders and may just wash off along the blood pressure gradient exiting in the venous system.

Taking another example would be a hypothetical situation of two dams impounding water from two river sources.



The horizontal energy exerted at the lower most portion of the dam is the same in both cases and is independent of the length of the river whether it is a 115 miles long or only 115

inches long. That is horizontal energy is equivalent to vertical energy but vertical energy is dependent on the pressure head, in this case - the vertical height of water column.

On similar lines the pressure exerted on the columns of Onyx causing it to climb up arterial pedicles remains the same at varying distances and depends only on the pressure head, in this case is the pressure transmitted to the catheter tip.

It is a known fact in fluid dynamics that pressure energy transmitted at one point is not completely recoverable as work energy at another site due to inevitable energy losses. This happens due to conversion of some part of pressure energy to heat generated due to friction which is irrecoverable. The amount of head losses depend on absolute pressure differences at both end, type of flow (laminar or turbulent), Surface properties of the conduit, physical properties of conduit like diameter, length and Tortousity of the conduit,

The Hagen Poiseuille law is a physical law that governs the equation for pressure drop happening in a case of a non compressible fluid in fully developed laminar flow occurring through a uniform cross section conduit of long length. It is given by

$$\Delta P \text{ is } \Delta P = \frac{8\mu LQ}{\pi r^4} \text{ ---- 1}$$

the pressure loss

L is the length of pipe

μ is the dynamic viscosity

Q is the volumetric flow rate

r is the radius

π is the mathematical constant Pi

Thus it can be seen that pressure losses are proportional to length, viscosity and flow rate and is inversely proportional to radius to the power of four.

The Onyx embolic flow within a microcatheter can be considered as a non compressible highly viscous non Newtonian fluid flowing through a small radius microcatheter with comparably very long distance (length of microcatheter compared to radius of same) at a constant volumetric flow rate.

This equation however assumes rotational symmetry of flow (Flow is "axisymmetric" that is in a straight course). When the fluid encounters change in directions (Flow becomes non axisymmetric) there is further loss of pressure energies as irrecoverable heat. Bends or curves along the path introduce turbulence with formation of eddies and whorls. In simple terms the channelization of streamlined flow into eddies and whorls require work to be done and when fluid does work, in accordance to law of conservation of energy the pressure energy of the fluid drops.

The resistance to flow is defined as the ratio of prime mover to the volume flow.

$$R = \frac{\text{pressure drop}}{\text{volume flow rate}} = \frac{-\Delta P}{\dot{V}} \quad \text{----- 2}$$

In fluid systems the prime mover is the pressure gradient. Resistance depends primarily on

1. **Radius**- as radius and cross sectional area increase the R reduces.
2. **Length** - As length increases the resistance increase.
3. **Viscosity**- As viscosity increases the resistance is increased.
4. **Turbulence**- As turbulence increases the resistance is increased.
5. **Surface friction** and roughness

Work is expended in overcoming resistance, which is converted to heat and is lost from the pressure energy of the fluid. In this study a statistical significant association was noted between presentation with NHND and a poor angiographic result. It is shown in previous animal and human studies that (82, 83) high pressure within the dural sinuses is an important predisposing factor for the development that perpetuates further high pressure once formed. It may be speculated that DAVFs presenting with NHND may be subgroup of patients within the DAVF group with a higher mean pressures within the dural sinuses close to the shunt in comparison to other presentations. Clinically also they present with global or focal deficits, raised ICP features and in general a model of physiologic disruption representing generalized perfusion abnormalities and disordered CSF hydrodynamics secondary to chronic venous hypertension. Lesions presenting in this manner are more often than otherwise located in the TS - torcular region (24). In our study group also 67% of lesions in NHND subgroup was located along SSS- to TS-SS junction. The implication of this raised pressure for treatment may be that it reduces the pressure gradient between the hub and tip of the microcatheter. Since the hub pressure is limited by the maximum rate of onyx injection, the Onyx exiting the tip at the fistula has to expend more of its pressure energy against the higher pressure found in this situation leaving less pressure energy for refluxing onyx up the arterial feeders.

The internal radius, length of the catheter and inner surface characteristics of catheter lumen remain a constant, since most of the times the hard ware used were mostly same or similar. It remains to be seen if any of these parameters can be manipulated to better suit the embolisation. However radius cannot be increased beyond a limit as it hampers distal catheter manipulation. Achieving meaningful reduction in length of catheters is not feasible as most of them are just long enough to reach the site of embolisation. The catheters depending on its braiding properties and physical properties may have different internal coefficients of friction. It may however be presumed that most catheters used for liquid embolic deposition

may have more or less similar construction and surface smoothness. Another parameter that affects the pressure head losses is viscosity. We have uniformly used Onyx 18 for all cases. However a case may be made here for a trial of lower viscosity onyx (Squid 12) in select cases following the initial plug creation wherein the embolisation is not progressing to plan with Onyx 18.



Viscosity and flow

Of the six variables (one demographic, one angiographic and 4 embolisation related), only two variables namely; type of pedicles embolized and number of 90 degree bends on lateral plane were statistically significant on multivariate analysis.

Multivariate regression analysis

Variable	p value	Odds ratio (OR)	95.0% C.I. for OR	
			LOWER	UPPER
Bends on lateral plane	0.012	3.230	1.298	8.040
Type of pedicle embolized	0.016	2.737	1.210	6.191

The effect of tortuosity on blood vessels both arteries and veins and its various clinical implications has been previously reported (84) (**Han H.C., 2012**) clinical correlates to aging, hypertension, Diabetes, genetic diseases, venous varicosities, ischemic heart disease and cerebro vascular disease have been probed. Many tortuosity indices taking into account the wavelength, amplitude of deviation, wave number and vessel calibre have been described based on evaluation of angiographic images. Many mechanical changes associated with arterial tortuosity have been demonstrated. Positive associations have been demonstrated with hypertension, loss of axial tension, loss of elastin in vessel walls and degradation of surrounding connective tissue. As a consequence of vessel tortuosity the resistance to flow can be markedly increased producing ischemic sequelae in target vascular territory (85-87). Thus it is plausible that the high flow conditions in DAVF produce vessel tortuosity and that the tortuosity can increase the resistance to flow. When a microcatheter is within a tortuous artery some of the bends are straightened out however some may still remain. To analyze the effect of residual curvature we assessed the tortuosity of vessels. For feasibility of calculation and standardization in all cases we sought to measure the number of 90 degree bends seen on simultaneous AP and lateral projections with microcatheter *insitu* in the final position of embolisation. The effects of 90 degree bends in coronary circulation with a physical basis of the same have been explored in many previous articles (88). Also technical difficulties posed by presence of 90 degree bends in access vessels to neuroendovascular targets has been addressed previously (89). However to the best of our current knowledge there is no literature dealing with effect of tortuosity on efficacy of endovascular liquid embolic permeation.

Due to the importance of 90 degree bends in pipe line constructions, machinery systems and Fluid dynamics in general, a lot of technical, theoretical and experimental data

have been garnered specifically addressing pressure head losses in 90 degree bends. Conventional and CFD studies have convincingly proved the effect of 90 degree bends on loss of pressure head (90-92), (93, 94). In general it is known that the more numerous, the more closely spaced and the more sharper the bends are the more energy losses occur and the more loss of pressure head occurs. An exact calculation of pressure loss or magnitude of loss in terms to the original pressure head was impossible to calculate with the facilities available to us, however the following discussion should be able to give some pointers (95, 96).

Head losses of fluid flowing through bends consists of 3 components:

- 1) Pressure loss by ordinary surface friction in the same length of tube in the absence of curve.
- 2) Excess pressure loss due to effects of eddy secondary flow on main flow d/t action of centrifugal force and friction forces within pipe.
- 3) Excess losses due to flow separation and subsequent expansion of separated streams along the inner and outer curvatures of bend

The relation is given by the equation:

$$P/\gamma = H = H_s + H_B + H_T,$$

$$H_B = \zeta \frac{U^2}{2g},$$

$$H_T = \theta \frac{U^2}{2g}, \text{ and}$$

$$H_s = \lambda_s \frac{l}{d} \frac{U^2}{2g},$$

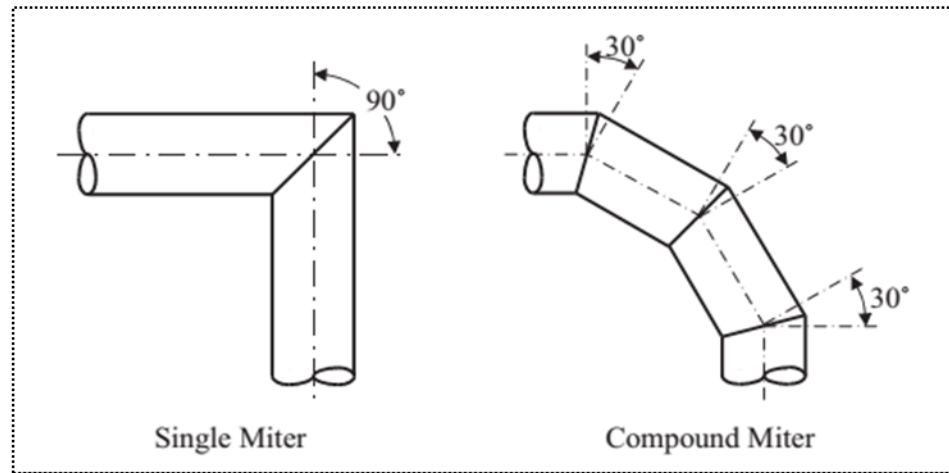
We may also write -

$$H = H_s + \eta \frac{U^2}{2g},$$

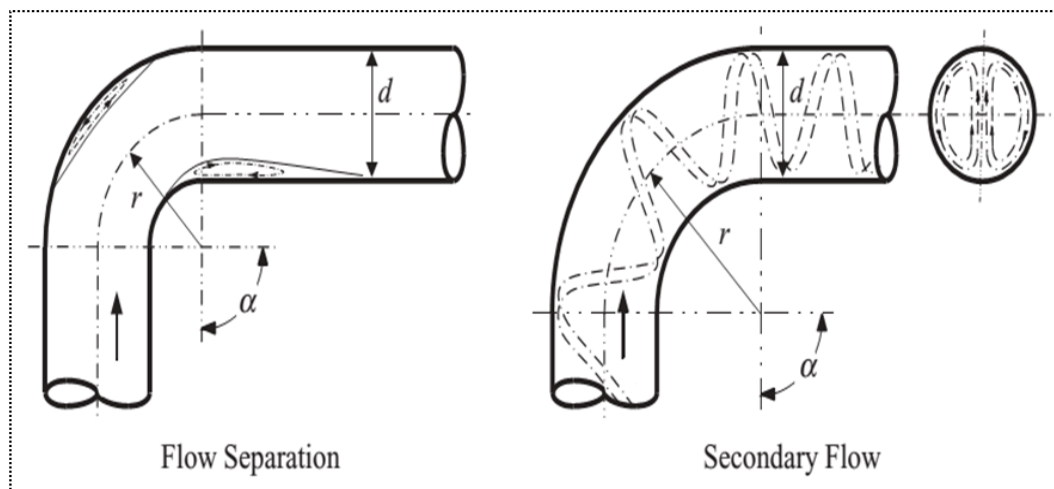
$$\eta = \zeta + \theta$$

$$\frac{P}{\gamma} = H = \lambda_s \frac{l}{d} \frac{U^2}{2g} + \zeta \frac{U^2}{2g} + \theta \frac{U^2}{2g},$$

Where η is the bend coefficient (Broadly speaking it depends on angle of deflection and radius ratio r/d of curvature of bend). On the one hand we have gentle bends with minimum bend radius ratio and smooth inner curve with minimum bend losses and on the other hand we have the other extreme we have the more tight bends with high radius ratio and sharp inner curve wherein the bend losses may be extreme.



For tight bends, flow separation and secondary flow are more important while for gentler bends, surface friction and secondary flow are more important. The clinical



implication for us regarding the study is exemplified by the two cases of failed embolisation of SSS fistulae which were attempted to be embolized through the frontal branches of MMA. Frontal branches of MMA are known to have three separate courses in relation to overlying calvarium. The MMA frontal branch may run in a

shallow groove mildly ridging the inner table a bridge type , or it may run in a deeper groove monorail type, or it may have a variable segment of tunneling through the calvarium in the pterional region (97). **Shimizu et al in 2008** (98) identified 75% incidence of tunneling in the pterional region of frontal branches of MMA with different surgical implications for dissections of MMA. Endovascular implication is the appearance of coupled miter bends in close succession along the course leading to difficult distal catheterization and increased fluid resistance.

Other notable but not statistically analyzed findings (lack of significant numbers)

The presence of isolated sinus segment shunts there were four such instances in our cases and all of them were successfully embolized, three in the first sitting itself and one in second sitting. In the fourth case in the first attempt an appropriate MMA feeder to the lesion was not identified, subsequently at the second attempt the shunt was treated completely via an appropriate MMA feeder.

The presence of final common channel: presence of a final common venous / arterial channel as a venous receptacle described by **Castaigne** et al in 2003 (80) in 10 of their patients. In our group 3 patients were identified with a common final channel, all of which were completely and successfully embolized.

6.8 TREATMENT OUTCOMES AND FOLLOW UP

We had 49 instances of trans arterial treatment for 43 patients over the period of last five years. The immediate cure rate was 85.7 % and the failure rate was 14 %. 8 patients underwent 2 sessions of onyx embolisation each. In 3/8 patients, separate anatomically non-contiguous lesions were embolized through separate feeders. In another three cases a second attempt was

done following initial failed embolisation two of which were eventually successful. In one patient a recurrence was detected at check DSA following successful treatment and was embolized a second time. In yet another case a second denovo appearing lesion visualized on Check DSA following successful embolisation of a lesion elsewhere was treated. Thus, an average of 1.16 embolization sessions was performed per patient.

Following the embolizations, transient mild complications were seen in 5 (10%) cases and major complications were seen in 2 (4%) cases. Procedure related complications were classified as mild if they did not make any change to management and only conservative management or observation was required and the complication was resolved prior to discharge in the next 72 -96 hours. Major complications was one which required an alteration in usual management care or mandated prolonged hospital admission more than norm for such a case. 4 incidences of transient and both cases of major complications occurred in patients that were completely embolized. Two patients showed significant spasm of internal maxillary artery following the procedures, both of which were resolved by intra-arterial instillation of nitro glycerine. One of the complications was seen in the form of repeated episodes of vomiting which was later controlled. One of our patient developed transient premature ventricular contractions in post op period. In one case there was mild epistaxis which resolved on its own once the anticoagulants were stopped. None of these events required any prolonged admission or extra medical management. This patient was revealed to have elevated levels of serum Phenytoin.

Both long term serious complications were seen in middle aged females that were successfully embolised. One patient following successful embolisation of right frontoparietal convexity Type 3 DAVF (NHND presentation) with Onyx as well as glue developed involuntary movement of limbs which persisted at the time of discharge and on later clinical evaluation. However she had improved from MRS 4 at initial presentation to MRS 3 at 6 months with

residual gait and speech difficulty. Her check DSA had revealed successful exclusion of shunt. The second patient underwent successful embolisation of Torcula fistula following Non aggressive presentation with orbital swelling. On day one of post op, she developed cortical blindness and had prolonged ICU admission during which time developed psychotic symptoms. This patient worsened from to MRS 4 at 6 months from an initial MRS of 2. Her check angiogram was not available for documentation of conclusive fistula exclusion.

Technical difficulties were observed in 8 cases (16.3 %). This did not include inability to navigate balloon across the fistulous site for venous protection. All technical difficulties were clinically inconsequential. There were two cases of rupture of microcatheters during embolisation with squid extravasation (One Sonic and one Marathon). There were three instances of significant amount of Onyx washing away into the venous side. Microcatheters were stuck in glue cast in 2 occasions. There was one episode of onyx reflux via anastomoses into APA with occlusion of same, which was however clinically silent. 4 of them occurred in successfully treated lesions giving a rate of technical problems arising in completely treated lesions of 4/43 (9%). On the other hand 4 out of 6 incompletely treated patients were associated with technical hitches giving a technical issue rate of 67%. This difference was statistically significant (p value =0.004). This result however may seem counterintuitive to the received wisdom of neurointerventional treatment which states that the longer a procedure takes to complete, the more chances of technical/ clinical complications arising out of it.

Following successful embolizations in 26/42 (62%) patients reported subjective improvement of symptoms, 14/42 (33%) insisted that there was no subjective change and 2/42 (4%) showed worsening (these are the cases that developed long term complications). In comparison in the failed cases 5/7 (71%) of cases reported no change in status, whereas 1/7 (14%) claimed subjective improvement and another 1/7 (14%) claimed worsening. The case of

worsening was seen in a male diabetic and CVT patient with multisite fistula that presented with H and following failed embolisation of left TS (ISS), torcula and SSS shunts presented with diplopia and occipital headaches and worsening of vision. This difference in subjective improvement between the two groups were not statistically significant ($p=0.061$).

Patients were assessed again clinically at one month, and 6 monthly thereafter for the first 2 years. Objective evaluation of functional status was done with MRS at 6 months.

At 6 months the 2 (4%) patients that had long term complications continued to have status worse in comparison to pre procedure. However 8 patients with same status post embolisation improved giving an overall tally of improved patients at 34/42 (80.1%). Same status tally reduced at the same time to 6/42 (14.3%). In the group of failed treatments the 5 patients that reported no change in status following embolisation continued to remain so. One patient that reported worsening underwent repeat embolisation after one month successfully to improve symptomatically. Thus there were 0% that remained worse and 2/5 (28%) reported some improvement subjectively at 6 months although the initial attempts were failure. In patients that improved check angiogram was available only in the patient that underwent subsequent embolisation. the other patient reported improvement in tinnitus with headache persisting. He was planned for repeat embolisation however has not undergone treatment as yet. At the end of 6 months the difference in symptomatic relief in patients that were successfully treated and otherwise was statistically significant ($p=0.004$), unlike in the immediate post procedure period. On patient with a failed embolisation of multisite fistula with no change in symptoms expired after 2 years due to unrelated issues (HIV positive with very low CD count).

6 months MRS

MRS score	Treated	Failed
0	29	0
1	4	1
2	4	3
3	3	3
4	2	0

Overall 6 month MRS scores were better in the completely treated group. Poor MRS > 2 was seen in 11.9 % of successfully treated group and in 43 % of failed group. This result was statistically significant ($p=0.003$). At 6 months the largest group of patients belonged to the MRS-0 group 29/59 (59%). Prior to procedure the largest group was MRS-2 (37%) with no patients in MRS -0 group. 6monthly follow up was available following last embolisation in 37/ 43 patients (31 complete and 6 failed treatments). Apart from the two long term complications there were 6 cases of new complaints - 3 episodes of vision reduction and 3 episodes of increases headache severity. 5/ 8 were seen in completely treated and 3 were seen in treatment failures. In 8 cases with new symptoms, Check DSA was available in 5 and 3/5 showed an occluded fistula at the embolized site and patent fistula at another site. There was no residual in one (With long term complication). One had a type 1 residual at the embolized site and another at a different location. The last patient had showed a residual fistula from a failed embolisation.

All patients following successful embolisation was scheduled for a check angiogram at 6 months. A check angiogram was available in 29 patients (25 successes and 4 failures). It was

not available in 20 patients (18 complete and 3 incomplete cases) as they have not turned up for angiograms. In all Check DSA were done at a mean duration of 9.68 (10.944) months (range from 1- 60 months). In 29 repeat angiograms the embolised fistula were staying completely occluded 21 cases (stable occlusions) of successful embolisations. In two cases (type 2A+B shunts) there were small residual Type 1 shunt persisting. However these were not considered as significant retreatment worthy lesions and were placed on follow up. Significant recurrences that were deemed as severe enough for retreatment were seen in 2 other cases (one was a right TS BV type 3 shunt with hemorrhagic initial presentation that was completely embolized and with no new symptoms and Check DSA demonstrated type 3 recurrent shunt. The second was another patient with a left TS type 2+B shunt with hemorrhagic presentation which was successfully treated and asymptomatic since then showed a recurrent aggressive fistula at the same site at check angiogram). The first patient is planned for repeat embolization and the second one was embolized subsequently with successful shunt devascularisation.

Clinical follow up was continued with OP visits every 6 months and telephonic interviews were conducted with patients and relatives who were in follow up at the end of the study. None of the patients in this group have thus far undergone any other alternative treatment following embolization here. The range of duration of follow up is from 4 -64 months with a mean of 22 (17.92) months. In a cumulative 90 patient year follow up there has been no documented or otherwise suspected case of intracranial hemorrhage following treatment.

Overall our treatment outcome at immediate post procedure is 88% which is comparable to most recent series dealing with transarterial onyx embolisation of DAVFs internationally as well as nationally. Our clinical complication rate is 4% and technical issues without clinical correlates is 16% which is again at par with most recent papers in this field. Recurrence rate in our series was 4% which is the lowest among all the recently reported series. Our rate of follow

up is 59% which is lower by comparison with most other series. This is in part, due to our insistence on angiographic demonstration of stable occlusion and also due to the fact that at least 6 patients (12%) are due to gets their angiograms at the time of writing as this is a recently concluded study.

Table for comparative overview

Series	No .of patients	Immediate cure	Follow up period	Complications/ Technical problems	Follow up percentage	Recurrence
Carlson, 2006 (99)	6	83.3	3 to 9	-	100	0
Cognard, 2008 (100)	30	80	3	-	83	0
Nogueira, 2008(101)	12	83.3	1 to 6	-	75	1
Steifel, 2009 (102)	28	72	1 to 15	-	28.6	0
Chew, 2009 (103)	12	75	0.2 to 12	-	75	0
Amiridze, 2009 (104)	9	100	6	-	100	0
Huang, 2009 (105)	14	85.7	3 to 12	-	57	0
Lv, 2009 (106)	40	62.5	3 to 8	-	72.5	0
Van Rooij, 2010 (107)	8	100	1.5 to 3	-	100	0
Zenteno, 2010 (108)	5	80	6	-	80	0
Natarajan, 2010 (109)	30	70	2 to 40	-	90	0
Maimon, 2011 (110)	17	94	3 to 12	-	47.1	0
Abud, 2011 (111)	42	81.8	6	-	95.2	0
De Keukeleire, 2011 (112)	20	85	4 to 14	-	70	1
Hu, 2011(113)	50	82	3 to 25	-	92	5
Chandra, 2014 (64)	40	95	12 to 80	14	73	0
Castilla, 2013 (69)	53	92.1	1 to 77	9.3	100	5
Saraf et al, 2010* (59)	25	84	-	8%	80% DSA	4%
Current study*	49 lesions	88%	4 to 64	4 % & 16%	59% DSA	4%

*Last two are studies from India**

CONCLUSIONS

DAVFs are one of the rarer but important vascular shunting lesions of the brain meningeal lining. Early recognition and prompt administration of treatment is of paramount importance in this disease. Angiographic diagnosis is the current gold standard and transarterial endo vascular Onyx embolisation is the current acceptable benchmark for management worldwide. Our study of 43 patients that underwent treatment this way is one of the bigger series in this direction. It is also the largest series from our country thus far. In this study we attempted to study, correlate, analyze and obtain inferences from our study population regarding the angiographic attributes of the lesion on their clinical demographic variables and the possibility of having a successful outcome following the treatment.

The important observations we made include:

- 1. Transarterial embolizations resulted in immediate angiographic cure rate of 87.75 % of instances with an overall major complication rate of only 4%. Transarterial single pedicle, single session embolisation through MMA was able to achieve an acceptable outcome in 79.6% of patients. The results thus obtained were noted to be stable in 92% when evaluated by DSA. None of the patients required any other form of treatment and in 90 patient years of follow up there were no incidences of documented Hemorrhage after treatment.**
- 2. Among clinical and angiographic attributes the following observations are made.**
 - ❖ The presence of CVT and DM although were seen more often in more severe grades of presentations and associated with multiplicity on angiographic**

evaluation and resistance to treatment, these associations could not assume statistical significance.

- ❖ **The statistically significant findings in clinical and angiographic evaluation and correlations were the following.**
- ❖ **Among all types of clinical presentations NHND had longest mean time to angiographic diagnosis.**
- ❖ **NHND was associated with a midline location of fistula, and H was associated with a lateral presentation.**
- ❖ **Arterial supply from anterior/posterior/ combined circulation is associated with Borden class of the lesions.**
- ❖ **Borden grades and no other classification schema were related to clinical presentation severity and also clinical presentation subtypes as NHND vs H.**
- ❖ **Topographic location at the tentorium was associated with presence of venous ectasiae and H presentation.**

3. TREATMENT cohort observations were:

The following attributes were associated with good immediate angiographic outcome (statistically significant):

- presentation with NHND was associated with poor outcome.**
- multiplicity with poor outcome**
- larger onyx volume administered with good outcome**
- use supplemental embolic with poor outcome**
- embolisation through MMA had a good outcome**

-
- number of 90 degree bends seen on lateral plane as well as total number of bends on Ap and lateral planes.

However on multivariate regression analysis only MMA feeder embolisation and number of bend on lateral plane (an index of tortuosity) were separately and independently associated with successful outcome following treatment. Together these two factors are independently able to predict the possibility of good outcome in a given case.

(i) Lacunae of Cognard Classification

Figure: 1

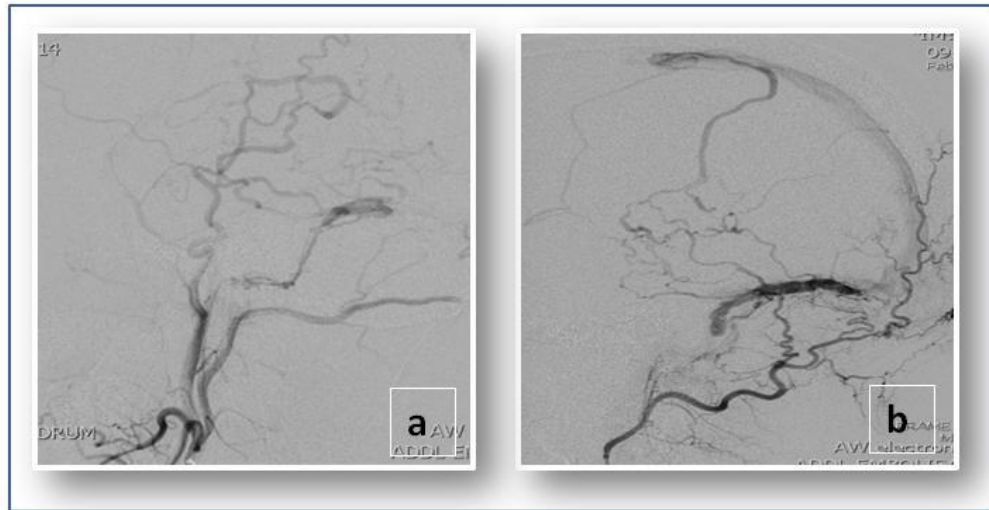


Fig 1 a & b: Lateral angiographic projections of a patient presenting with haemorrhage shows shunt from left OA and APA into an isolated segment of TS which further refluxes almost with no phase offset into cortical veins and drains secondarily through SSS. Such lesions are Borden type 3 but Cognard class is not defined. We have considered them as intermediate in severity between Type 2B and Type 3.

Figure: 2

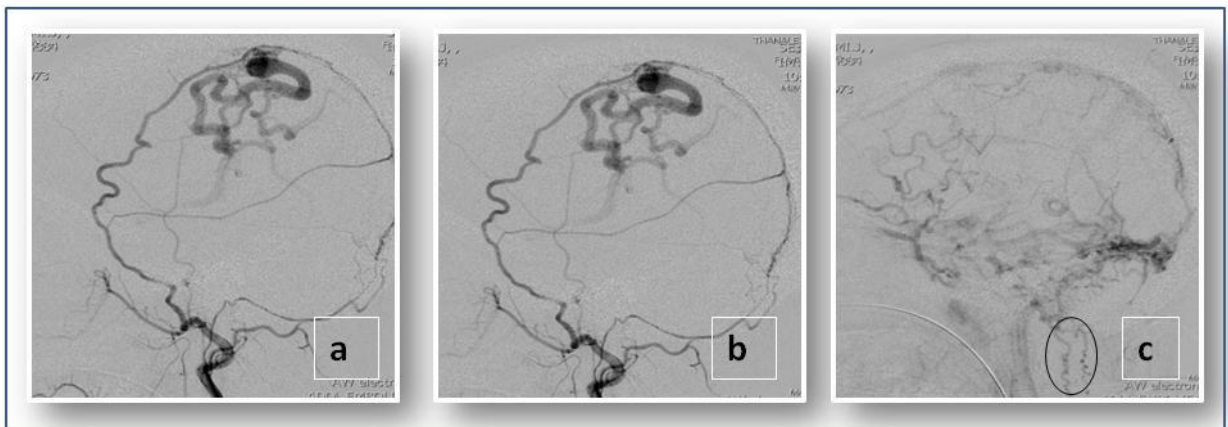
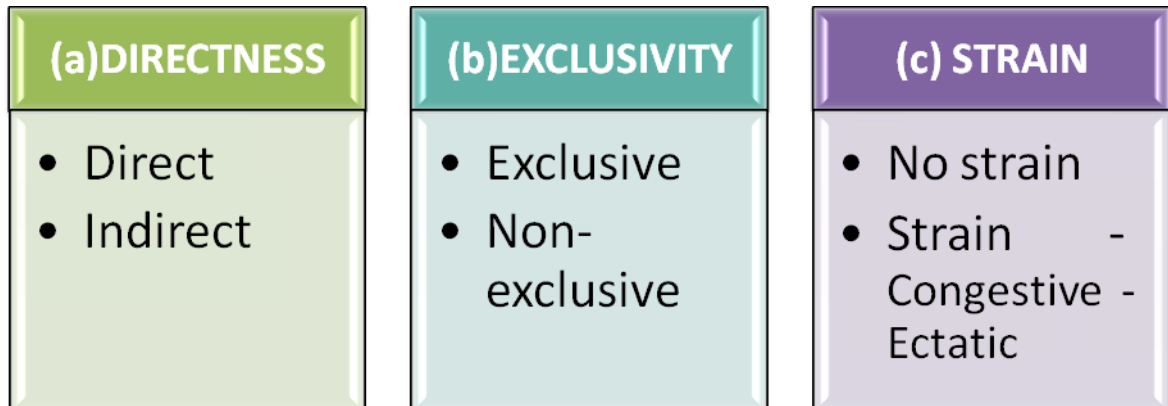


Fig 2: Lateral serial angiographic projections in patient with haemorrhage shows direct and exclusive shunt into a parietal convexity cortical veins close to insertion at the SSS classified here as a type 3 Cognard. There is extensive CVR with drainage secondarily via superficial middle cerebral veins and notably perimedullary reflux. It is not clear whether to include such reflux as a type 5 associated perimedullary drainage. The original article refers to shunt in the vicinity of Foramen magnum or tentorial region draining directly into spinal venous system as Type 5.

(ii) The DES Concept

Figure: 3



(A) DIRECTNESS

Figure: 4, 5, 6

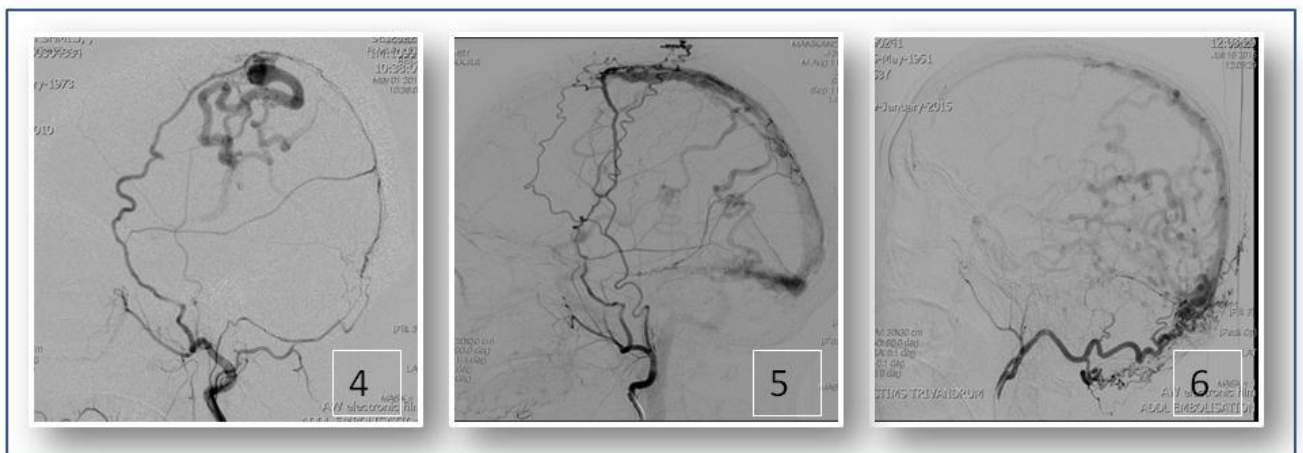


Figure 3: Lateral projection of an IMAx artery showing 'direct' shunting into a convexity cortical vein without interposition of a dural sinus. There is exclusive drainage to cortical veins, the connection to the SSS having been blocked due to the high flow vasculopathy.

Figure 4: Lateral projection from an IMAx artery in another patient shows 'indirectness' with shunt into Anterior SSS from which CVR is seen to occur. Drainage in this situation is occurring primarily via dural sinus along with some drainage occurring retrogradeley through cortical veins.

Figure 5: Lateral projection of an OA injection- indirect drainage into the torcula with reflux retrogradeley into SSS and Cortical veins. The drainage in this situation is predominantly via cortical veins.

Figure: 7

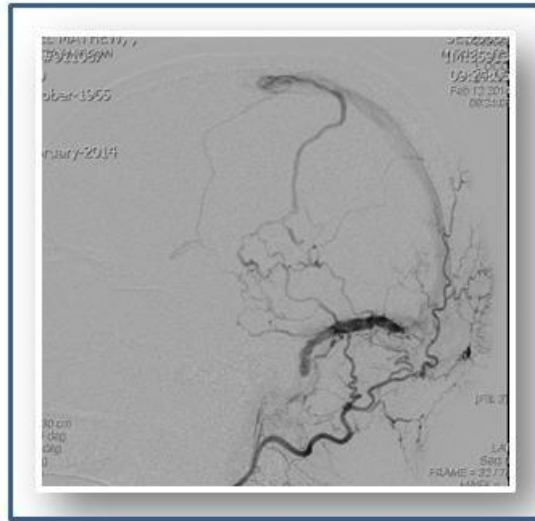


Figure 7 shows a lateral projection of an OA injection with shunt into an isolated segment of TS- the ISS or isolated sinus shunt. This represents an intermediate situation of 'directness' wherein the cortical venous reflux occurs almost immediately after the dural segment receives shunt and further drainage is exclusive through cortical veins. The dural system is only involved in secondary drainage.

(B) EXCLUSIVITY

Figure: 8

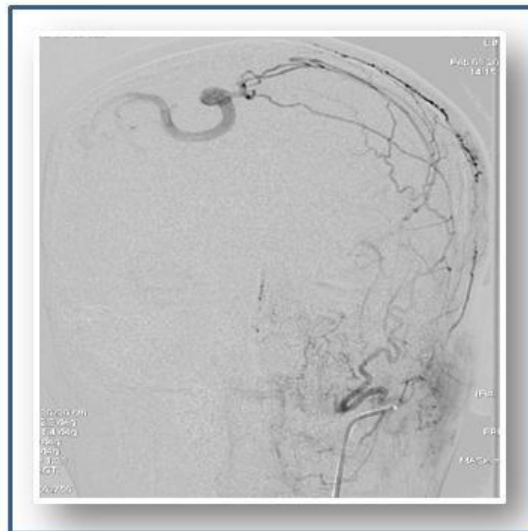


Figure 8: AP projection of left ECA projection showing the meningeal arteries shunting into a contra lateral convexity cortical vein close to SSS. The SSS takes no part in drainage of the shunt and is 'exclusively' serviced by the cortical vein.

Figure: 9

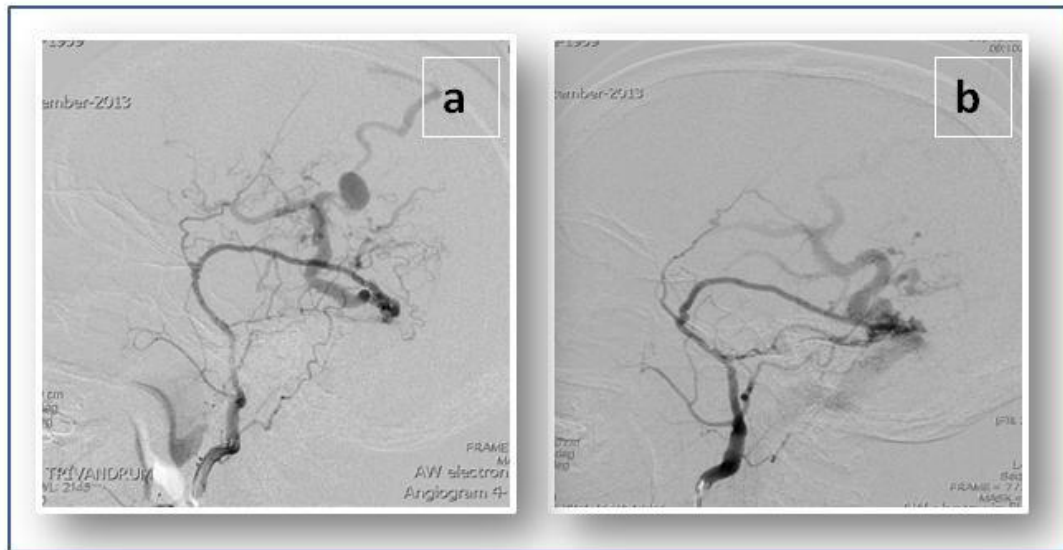


Figure 9 a & b: Lateral angiographic projections from either of ECA from a patient with bilateral shunt shows direct shunting exclusively in Fig 9a and non exclusively in Fig 9b with additional shunting through sigmoid sinus and jugular vein.

(C) STRAIN

Figure: 10



Figure 10: Lateral angiographic projection of OA shows shunt into left TS with retrograde CVR into normal sized veins without signs of 'pressure' or 'volume' overwhelming.

Figure: 11

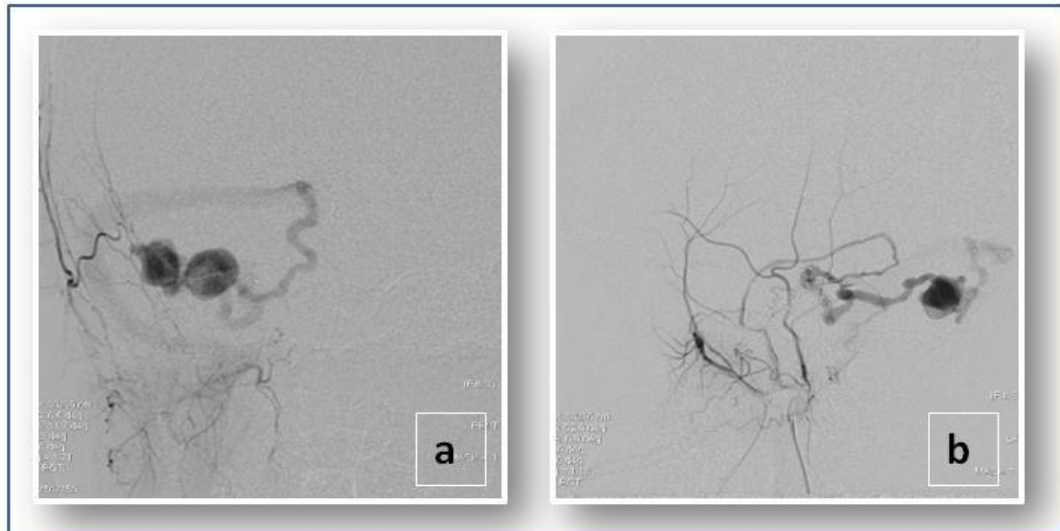


Figure 11 a & b: AP and lateral projections of IMAx injection showing presence of ectatic venous strain (pressure strain) on the venous side of direct dural fistula of a superior petrosal shunt draining secondarily to the torcula.

Figure: 13

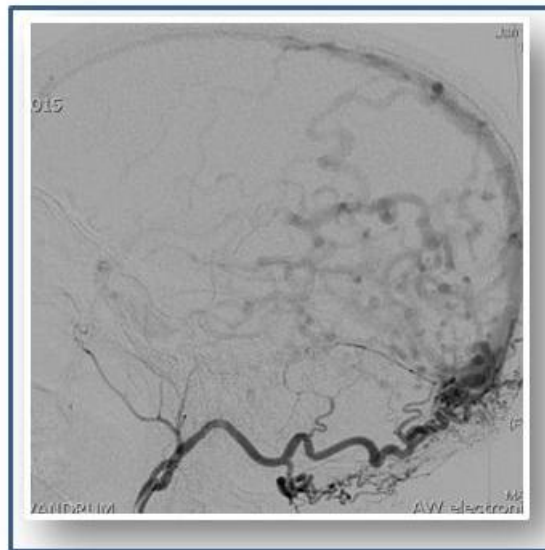


Figure 13: Lateral projection of an Occipital artery shows extensive prominent CVR showing congestive type of venous strain (volume strain).

(iii) UNUSUAL LESIONS

Figure: 14 MCF fistula

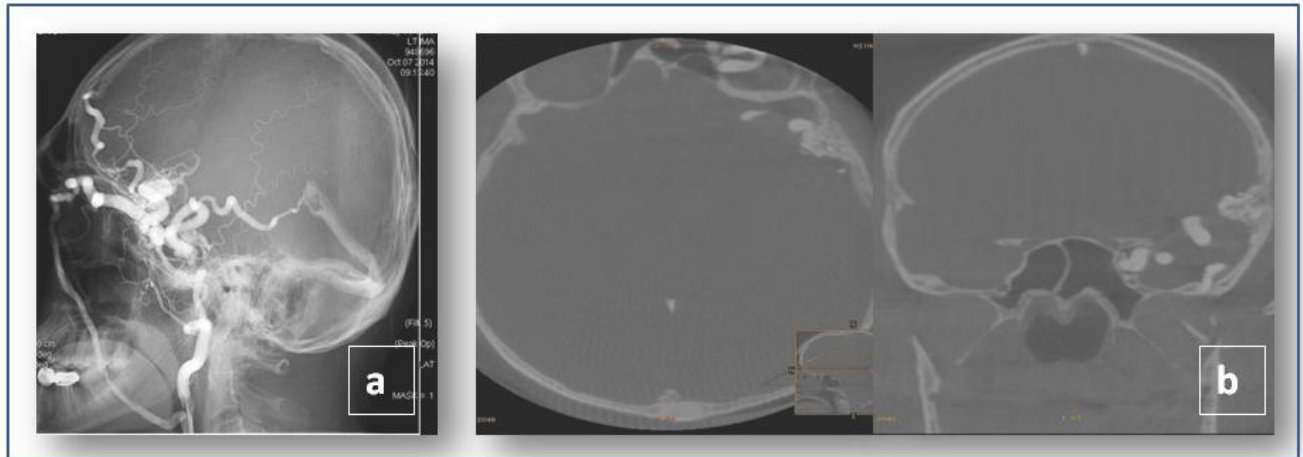


Figure 14 a & b: Lateral unsubtracted projection of ImaX injection in male patient presenting with redness of eye shows a fistula along the sphenoid wing in left Middle cranial fossa. There is reflux into superior ophthalmic veins accounting for patient symptoms and extensive CVR into the frontal cortical veins and also into the deep system via internal cerebral vein. Fig 14 b: panel shows axial and coronal reconstructed CT scans from Dyna CT acquisition showing the location of fistula along the sphenoid ridge on the left side.

Figure: 15

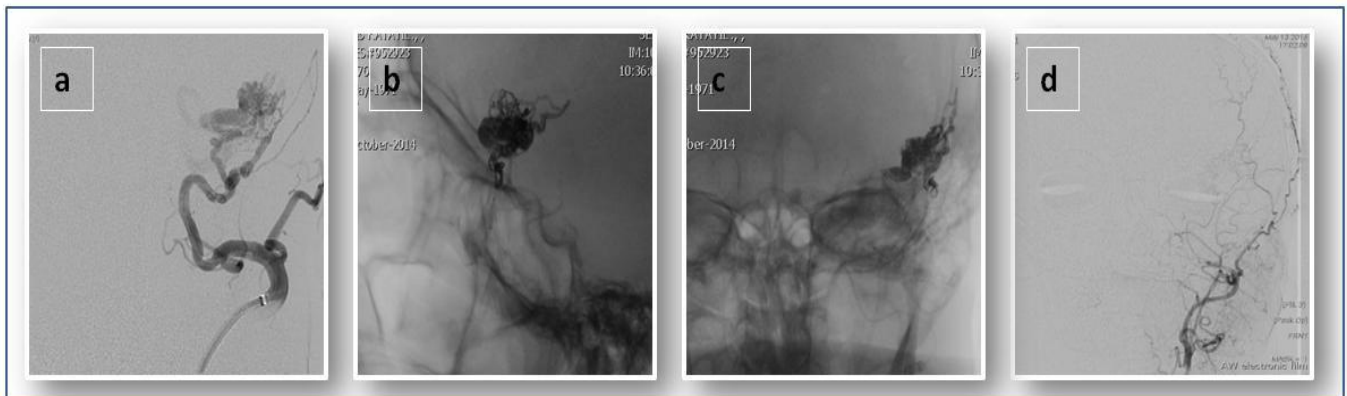


Figure:15 The lesion was successfully and completely embolised by single pedicle onyx injection of an MMA branch. Fig 15 a & d are the AP projections of left IMAx artery prior to and 6 months after embolisation respectively. Fig 15 b & c are unsubtracted orthogonal projections post-embolisation showing the embolic cast.

Figure:16 Tentorial Fistula

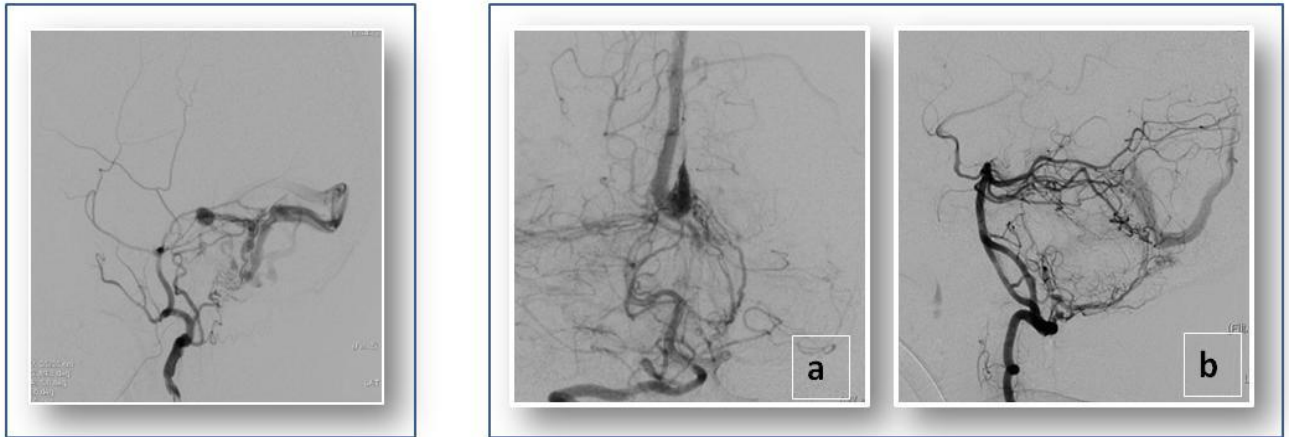


Figure 16 : Lateral projection from IMAx artery showing a lateral tentorial fistula of superior petrosal sinus. Fig 15 a&b shows orthogonal projections from VA injections showing a marginal tentorial fistula (falcotentorial region with feeders from the PCA and drainage to straight sinus. Both were successfully embolised (images not shown).

(iv) **MANIFESTATIONS OF HIGH PRESSURE AND VOLUME ON ARTERIES
(HIGH FLOW ANGIOPATHIC CHANGES)**

Figure: 17



Figure: 18

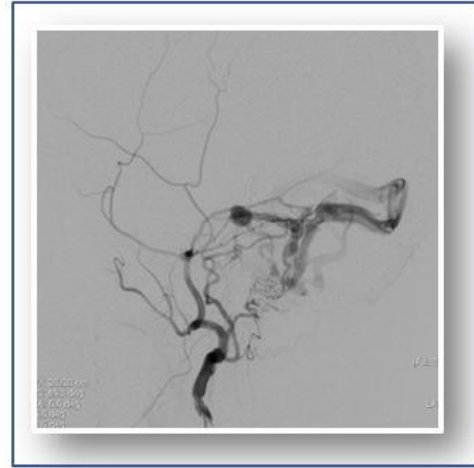


Figure 17: Lateral angiographic projection of IMAx injection showing two aneurysms on the MMA feeder to a large fistulous shunt to TS.

Figure 18: Lateral angiographic projection of IMAx injection shows a venous ectasia in a superior petrosal sinus shunt. Both may be substrate of patients symptoms. These changes are expected to cease to exist once the primary shunt is disconnected, however may at times require directed treatment like in the first case the aneurysms that were causing erosion of calvarium and presenting as pulsatile masses were embolised with coils and few cc of Onyx.

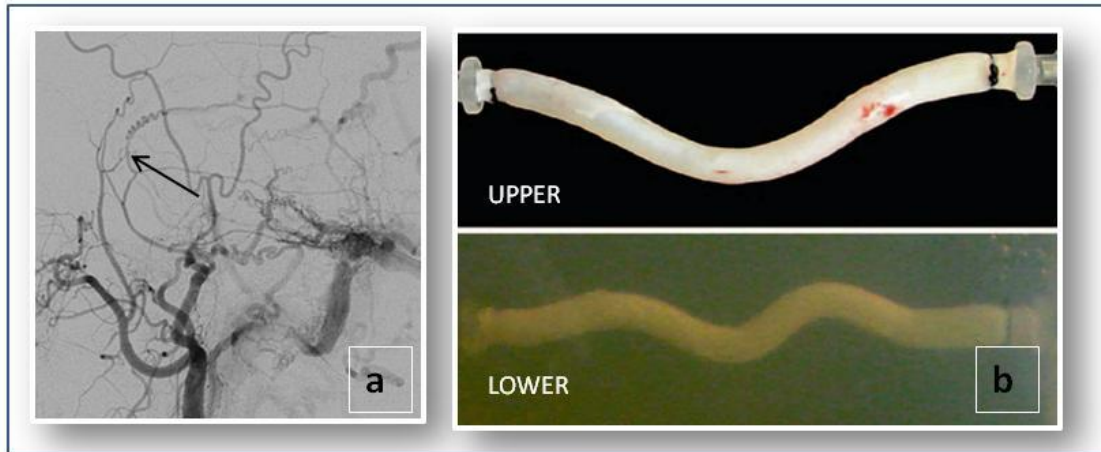
Figure:19



Figure 18: Unsubtracted latera view from post embolic acquisition of TS fistula shows cast within 2 parallel structures one of which is the TS and the other is a

parallel veous channel that was the primary shunt recipient and is believed to have opened up in response to excessive volume strain.

Figure:20



angiographic projection of ImaX injection showing excessive tortuosity (black arrow) of a normally straightforward meningeal artery. Figure 20(b) The panel from ex vivo experiment of an artery within a supporting matrix under elevated internal pressure buckling into tortuous shapes. (upper panel) Under an internal pressure (140 mm Hg) beyond its critical pressure (80 mm Hg) in PBS solution. b(lower panel) Under an internal pressure (230 mm Hg) beyond its critical pressure (150 mm Hg) in gelatin.

Fig 19 b:(Image from Hai-Chao Han : *Twisted Blood Vessels: Symptoms, Etiology and Biomechanical Mechanisms* : *J Vasc Res* 2012;49:185–197)

(v) FAILED CASES:
a) TORUOSITY

Figure: 21

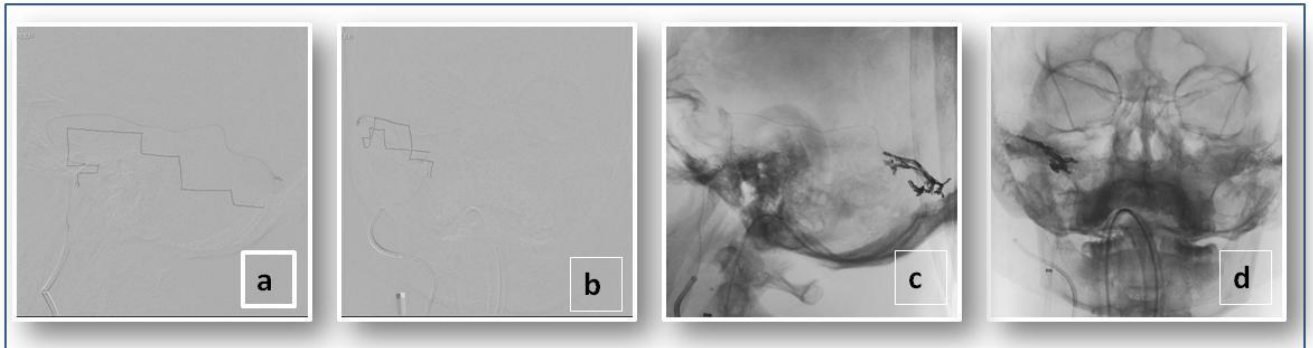


Figure:22

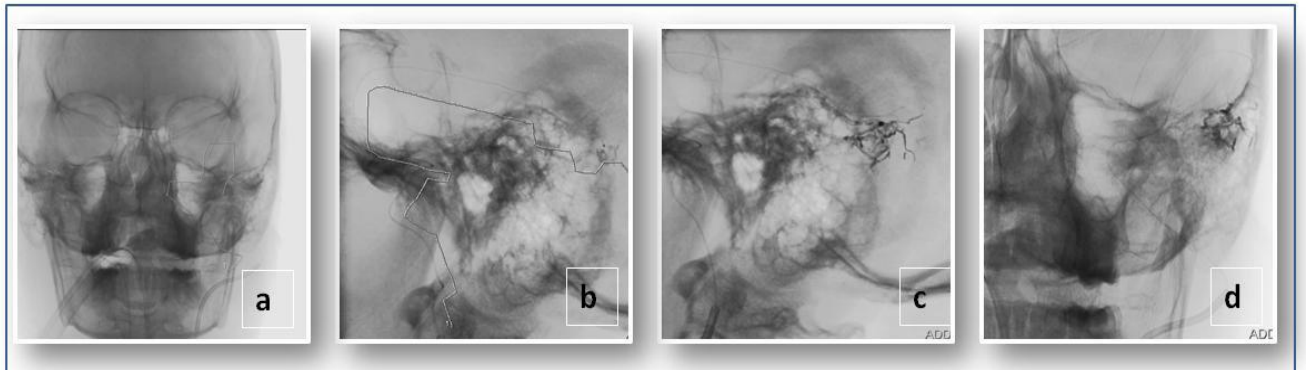


Figure: 23

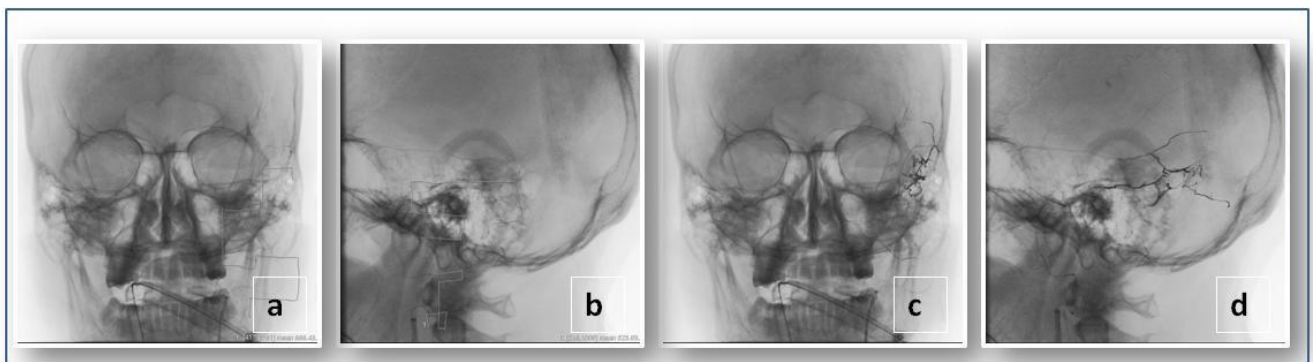


Figure 21 to 23: Cases of failed embolizations the first two images in each case shows orthogonal projections of micro catheter injections which shows excessive tortuosity (90 degree bends)with possible head loss of exiting onyx column.The last two images in each case shows unsubtracted orthogonal projection images showing minimal embolic casting of nidus.

Figure: 24

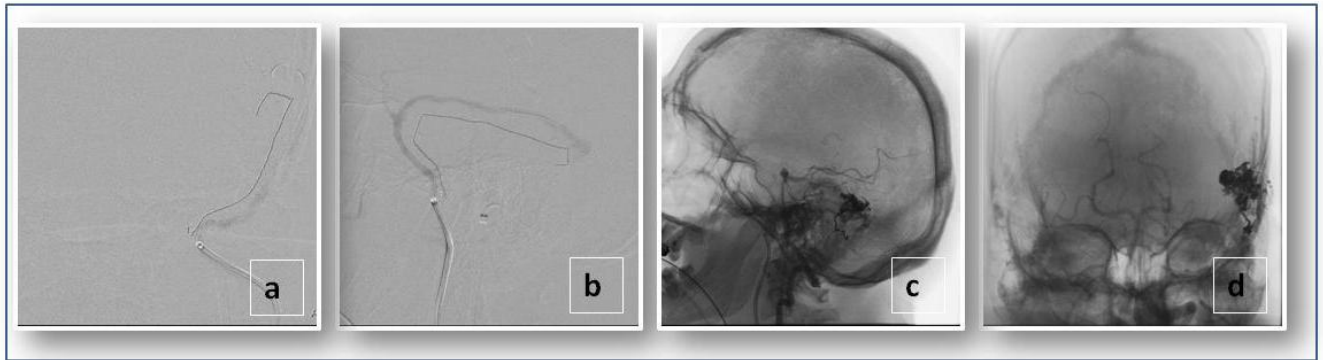


Figure: 25

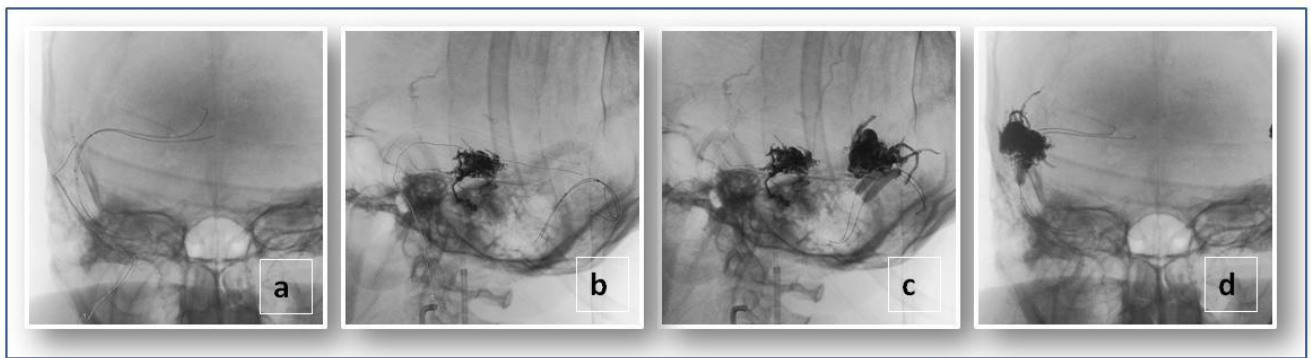


Figure: 24, 25 Straight forward course of MMA with relatively few 90 degree bends. The substantial embolic cast on orthogonal unsubtracted images seen on last c & d images of both cases bear testimony to effectiveness of embolisations (compared with the failed cases shown previously).

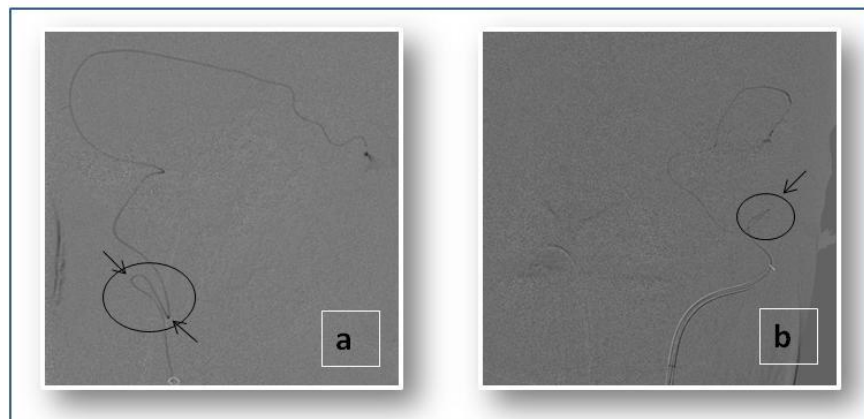


Figure: 26

Figure 26: Orthogonal subtracted images from microcatheter injection images from a failed case shows an extreme case of bending showing closely placed coupled bends in series and in opposite direction. In such cases the principles of fluid dynamics mandate that the pressure head losses is even more than the arithmetic sum of component bends if they were widely apart.

Figure: 27



Figure: 28

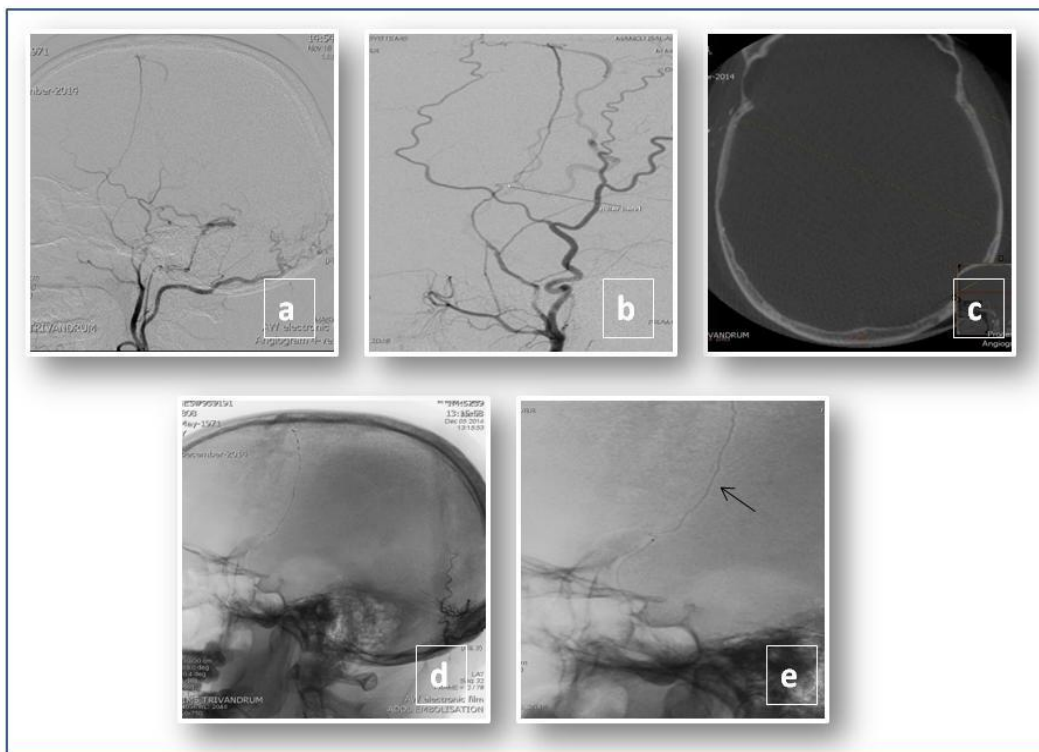


Figure 27, 28: shows two other failed cases wherein there is presence of another extreme of tortuosity- the intracalvarial course of frontal branch of MMA causing miter bends. Lateral angiographic images from IMaX injections show deep tight kinking (black arrows) as they pass through tunnelled segments indicated on Dyna CT reconstructed images. Notice that on orthogonal projections the microcatheters could not be passed distal to these miter bends. Post embolization unsubtracted images show a thin spattering of minimal embolic staining only (circle in the first patient and arrow in the seconds)

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INTRODUCTION: The clinical presentation, course, and management of acute myeloid leukemia (AML) are heterogeneous. This review summarizes the current understanding of AML, including its epidemiology, pathogenesis, and clinical features. The review also discusses the latest advances in the diagnosis and management of AML, with a focus on the use of targeted therapies and stem cell transplantation. The review is organized into several sections, including: 1) Epidemiology and Pathogenesis, 2) Clinical Presentation and Diagnosis, 3) Management, and 4) Prognosis. The review is intended for healthcare professionals and researchers in the field of hematology and oncology.

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LIST OF ABBREVIATIONS

ApA : Ascending pharyngeal Artery
BV: Bridging Vein
CS : Cavernous Sinus
CT : Computed tomography
CV: Cortical Vein
CVR : Cortical venous reflux
CVT: Cortical venous thrombosis
DCCF : Dural Carotico Cavernous Fistula
DES: Directness Exclusivity Strain
DSA : Digital Subtraction Angiography
DMSO: Dimethyl Sulfoxide
EV: Emissary Vein
EVOH: Ethinyl Vinyl Alcohol Copolymer
DM : Diabetes Mellitus
ECA : External Carotid artery
EDS :Ehler's Danlos Syndrome
HT : Hypertension
H: Hemorrhagic presentation
ICA : Internal Carotid Artery
I: Intermediate presentation
IVH: Intraventricular Hemorrhage
ICH : Intracranial Hemorrhage
IJV :Internal Jugular Vein
ICV : Internal Cerebral Vein
IMaX : Internal Maxillary Artery
IPS : Inferior Petrosal Sinus
IOY : Inferior Ophthalmic vein
MRI : Magnetic Resonance Imaging
MMA : Middle Meningeal Artery
NBCA : n Butyl Cyanoacrylate
NA: Non Aggressive presentation
NHND: Non Hemorrhagic Neurologic Deficit
OA : Occipital Artery
PVA : Poly vinyl alcohol
STA: Superficial Temporal Artery
SOV : Superior Ophthalmic vein
SSS : Superior Sagittal Sinus
St S : Straight Sinus
SS : Sigmoid Sinus
SPS: Superior petrosal sinus
TS :Transverse Sinus
VA : Vertebral Artery

PROFORMA

CLINICAL:
Age:
Sex:
Hospital no :
Chief complaints/duration of symptoms:
History of presenting complaints:
Past history/treatment history:

Examination :
General examination:
System examination: CVS Respiratory GIT/GUT CNS
Other /Local examination:
<u>IMAGING REVIEW</u> USG- CT/CT ANGIO: MRI/MRA:

EMBOLISATION DETAILS:

- Agent used :Onyx, (volume in ml)

- supplemental embolics if any

- Procedure duration

- No and type of pedicles embolised

- Angiographic result

Complete/incomplete

- Hardware used.

Guiding sheath

Angio catheter

Micro catheters

Micro wires

- complications / technical difficulties if any

- Heparin Dose

Reversal if any required

FOLLOW UP CLINICAL

Immediate post procedure- Relief from symptoms

Stability of result at 6 months

Persisting symptoms if any

Improvement/worsening if any

New symptoms if any

FOLLOW UP ANGIOGRAPHY at 6 months:

Whether available or not

Residual lesion : Present/absent

Arterial feeders

Venous drainage

KEY TO MASTER CHART

- 1) Age: 0 to 30 = 1, 31 to 60 = 2, 60 to 90 = 3
- 2) Sex : male=1, female=2
- 3) Clinical features nhnd= 1, h=2, i =3, na= 4
- 4) Clinical features aggressiveness : nhnd & h =1, i=2, na =3
- 5) Duration of symptoms 1month=1, 1 to 2 months=2, > 2 months=3
- 6) Co morbid illnesses : none =0 DM =1, CVT= 2, HTN=3,other =4
- 7) Dm: present =1, absent =2
- 8) CVT : present =1, absent= 2
- 9) Side : left = 1, right = 2, midline = 3
- 10) SSS to TS , SS junction (1), SS to IJV (2), transspatial including Ts SS junction (9 = 3) , MCF (4), convexity bridging veins (5), tentorial (16)
- 11) external vs internal : External only = 1, internal only = 2, external and internal = 3
- 12) left vs right : left =1, right =1, bilateral =3
- 13) multiplicity : single =1, > 1 site =2
- 14) unilateral vs bilateral : u/l =1, b/l =2
- 15) anterior vs posterior: anterior =1 , posterior = 2, anterior + posterior =3
- 16) embryologic : DE=1, VE= 2, Le=3, DE + VE = 4
- 17) DES: no CVR=0, nDnEnS=1, nDnES=2, nDnES=3, nDES=4, DnEnS=5, DnES=6, DEnS=7, DES=8
- 18) Cognard : , Type 1=1, Type 2A=2, Type 2B=3, Type 2 A+B =4, type 3= 5, Type 4= 6
- 19) CVR: present =1,absent 2
- 20) Venous congestion : present =1, absent 2
- 21) Venous ectasia: present =1, absent =2
- 22) Dural sinus status : stenosis/occlusion : present =1, absent 2
- 23) Supplemental embolics for fistula :present = 1, absent =2, venous protection =3
- 24) Feeder : MMA=1, OA=2, ApA=3, other =4, mma +oa=5
- 25) Angiographic result : complete/ near total =1 , incomplete =2
- 26) Complications : none =0, transient= 1, long lasting=2
- 27) Technical issues: seen=1 , none seen =2
- 28) Immediate post procedure :worsened =0, status quo =1 , improvement =2
- 29) Follow up DSA : available =1, not done=2.
- 30) Residual lesion on DSA ;0 = not done, 1 =no to minimal shunt, 2 =reccurence