ENDOVASCULAR TREATMENT OF AVMS

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Arteriovenous Malformations

- Congenital abnormal collection of blood vessels wherein blood flows from arterial circulation directly into venous circulation, bypassing capillary beds
- Incidence/Prevalence not definitively studied, but estimated incidence is 1.1/100,000 in population-based studies
- Slight male preponderance
- Average age diagnosed ~33 years old
Arteriovenous Malformations
Presentation/Clinical Features

- Hemorrhage (50%)
  - Intracerebral, subarachnoid, intraventricular
- Seizures (20-25%)
- Headache (15%)
- Mass effect - direct compression/swelling of adjacent structures
- Ischemia - preferential flow through the AVM due to decreased resistance, causing hypoperfusion of surrounding brain parenchyma
Why Treat AVMs

- 2-4% annual risk of rupture
  - Independent risk factors for rupture:
    - Associated aneurysm (feeding artery, intranidal)
    - Previous rupture
    - Small AVM size
    - Deep venous drainage
  - Goal is to determine risk of conservative treatment vs risk of intervention
    - ARUBA trial – A Randomized Trial of Unruptured Brain AVMs
### Spetzler-Martin Classification

- **Size**
  - Small (< 3cm) 1
  - Medium (3-6 cm) 2
  - Large (> 6 cm) 3

- **Eloquence of adjacent brain**
  - Non-eloquent 0
  - Eloquent 1

- **Pattern of venous drainage**
  - Superficial only 0
  - Deep 1
Pretherapeutic Evaluation

- **Noninvasive Techniques**
  - CT/CTA
  - MRI/MRA
  - fMRI
    - Local increase in cerebral blood flow and volume after stimulation of eloquent cortex

- **Diffusion-Tensor Imaging**
  - Visualization of white matter pathways and their relationship to AVM
Imaging
Imaging

Figure 1
Pretherapeutic Evaluation

- Invasive Techniques
  - Provocative Injection Testing (Wada’s Test)
    - Amobarbital sodium injection of selective feeding vessels to predict/avoid post-embolization deficits
Pretherapeutic Evaluation

- **Angiography**
  - Arterial feeders, size of AVM, nidus characteristics, drainage pattern
  - Other anatomical characteristics
    - deep location, deep venous drainage pattern, presence of a single draining vein, venous stenosis, eloquent location and diameter of AVM
  - Associated aneurysms (feeding artery, intranidal, circle of Willis, venous)
  - Pseudoaneurysms
  - AVM-associated AV Fistulas
Pretherapeutic Evaluation

- **Angiography**
  - Angiogram following hemorrhage can result in false negative secondary to nidus compression
  - Gold standard is follow-up angiogram 3 months after hemorrhage for detection of AVM
Perioperative/Anesthetic Considerations

- Continuous arterial transductions
  - Deliberate systemic hypotension
  - General anesthesia
  - adenosine-induced cardiac pause – slow flow through AVM for controlled deposition of embolic material

- Pulse Oximeter Ipsilateral to femoral sheath
  - Vessel obstruction, thromboemboli, over-compression following sheath removal

- Foley catheter- fluid management

- (Supplemental O2 // Nasopharyngeal airways for those under sedative-hypnotic agent)
Anatomy-Based Management

- Neuroanatomy to understand at-risk territories
- Done under general anesthesia
  - Patient comfort
  - Ensures motionless patient
- Theoretically, because AVM has no functional intervening tissue, embolization of appropriate vessels should not cause functional deficit
- Neurophysiologic monitoring
  - SSEP/EEG
Physiology-Based Management

- Evaluation of functional anatomy during procedure
- Requires intravenous anesthesia with short-acting agents (propofol, midazolam)
- Wide variability and cortical reorganization described in AVM patients
Endovascular Technique

- Preoperative discussion
- Vascular access with No. 7 Fr gauge sheath into femoral artery via Seldinger technique
- Anticoagulation algorithms to prevent thromboembolic complications
  - JHN-continuous heparinized flush, no bolus
- No. 6 Fr gauge guiding catheter introduced into ICA or vertebral artery
- Flow-directed/flow-assisted microcatheters to reach intranidal target
  - Variability in flexibility, torque, maneuverability, and responsiveness.
Identification of Embolization Point

- Tip of catheter directly into nidus
- Tip of catheter into feeder that does not share supply with adjacent normal brain
  - If normal brain at risk, pretherapeutic/intraoperative functional evaluation can be performed to avoid neurologic deficit from embolization
Injection of Embolic Material

- Polyvinyl alcohol
- n-butyl cyanoacrylate
- Onyx
- Ethibloc
- Silk
- Microcoils
- Combination
Polyvinyl Alcohol (PVA)

- Available in different sizes based on size of target vessels
- Slower occlusion than liquid embolic agents
- Occlude low-pressure shunts first
  - Results in increase in intranidal vessel pressure → hemorrhage risk prior to nidal obliteration
- High recanalization rates
  - Development of collateral feeders secondary to proximal occlusion of AVM with large size particles may contribute to this high rate
- Used with success preoperatively to reduce flow prior to open or radiosurgical treatment
**n-BCA**

- Liquid monomer that permanently polymerizes to a solid compound after contact with anions
- Occlusion by initiation of inflammatory endothelial response
- Combined with Ethiodal (iodine-based oil) to make lesion opaque on X-rays
  - Tantalum powder added to increase opacity (currently less common)
n-BCA

- Viscosity and Polymerization time
  - Increasing Ethiodal concentration increases viscosity and delays polymerization
    - Delayed polymerization helpful in lesions that exhibit slow flow
    - Increased viscosity delays transit within lesion
  - Temperature, homogeneity of mixture, and changes in pH of solution also influence polymerization time
n-BCA

- Acetic acid and glacial acid to decrease pH
  - Delays polymerization without compromising viscosity
- Dextrose 5%
  - Delays polymerization time by delaying contact of blood with n-BCA
Factors that influence choice of viscosity and polymerization time:
- Distance between microcatheter and nidus
- Tortuosity of vessels
- Intracranial flow
n-BCA

- 1:1 dilution (nBCA:oil) used when flow is very fast and catheter is close to nidus
“Flow Control” – Microcatheter occludes distal blood flow as it reaches smaller vessels, thus preventing blood from contacting glue, allowing for distal penetration

Injection stops when glue reaches venous system through nidus or there is backflow towards the catheter

Remove catheter quickly to prevent catheter retention
Onyx

- Ethylene-vinyl alcohol copolymer (EVOH) mixed in dimethyl-sulfoxide (DMSO) solvent
- Tantalum for radiopacity
- Lower concentrations of EVOH $\rightarrow$ decreased viscosity
- Soft and nonadhesive mass that does not fragment
  - Increased embolization from single catheter position
  - Allows for angiography between injections
- Nonabsorbable $\rightarrow$ permanent occlusion
Onyx

- Pitfalls
  - Angiotoxicity related to DMSO
    - swine rete mirabilis embolization model report risk of mild transient acute vasospasm
  - Separation of tantalum from Onyx
    - Increases difficulty of viewing smaller feeding pedicles
Treatment Objectives

- Embolization for definitive cure
- Embolization as a precursor for definitive operative resection
- Embolization as a precursor for radiosurgery
- Embolization as palliative treatment for progressive debilitating symptoms
- Target embolization of high risk lesions
Treatment Objectives

- Embolization for definitive cure
  - N-BCA complete obliteration rates (~10%)
    - Deruty, et al – 5% but primarily used in high-grade AVM
    - Vinuela, et al – 9.9% in small to medium AVM with less than 4 pedicles (405 pts)
    - Lundqvist, et al – 13%
    - Valavanis and Yasargil – 40% in 387 consecutive patients
    - Gobin – 11.2% in patients after embolization prior to radiosurgery (125 pts who were poor surgical candidates)
Treatment Objectives

- Embolization for definitive cure
  - Onyx complete obliteration rates
    - Perez-Higueras, et al – 22% in series of 45 patients
    - Pierot, et al – 4.2% in series of 48 patients
    - Leonardi, et al – 5.9% among 34 pts SM III-IV
    - van Rooij, et al – 15.9% among 44 pts SM I-II
    - Weber, et al – 20% among 93 patients
    - Mounayer, et al – 27.7% among 94 patients treated with Onyx, n-BCA, or combination
    - Panagiotopoulos – 24.4% among 82 pts
  - Reconstitution of flow to AVM nidus can occur through dilation of pre-existent collateralization
    - Rare cases reported for n-BCA
    - Recent reports of reperfusion for Onyx (Perez-Higuera, Weber, Panagiotopoulos)
Treatment Objectives

- Anatomic features predictive of angiographic cure with n-BCA (Valavanis and Christoforidis)
  - Direct or dominant feeding arteries
  - Monocompartmental nidus
  - Dominant fistulous component of nidus without perinidal angiogenesis

- Anatomic features predictive of angiographic cure with Onyx
  - Supratentorial and cortical location
  - Compact and plexiform nidus
  - Small number of supplying(direct) feeders
  - 1 superficial draining vein
Case 1

- 26 yo female PMH migraines who presented with a seizure two years ago. Imaging revealed R temporoparietal AVM fed by MCA and PCA branches, with superficial drainage veins
Case 1
Patient underwent staged embolization with n-BCA over three sessions to achieve angiographic obliteration of AVM
Embolization as a precursor for definitive operative resection

Goals:
- Reduction of size of nidus
- Occlusion of deep arterial feeding vessels which may be surgically inaccessible
- Treatment of intranidal aneurysms and high-flow fistulas to promote progressive nidus thrombosis
- Reduce blood loss, improve operative time, convert high Spetzler-Martin AVMs to lower grade lesions → reduce morbidity and mortality
Treatment Objectives

- Embolization as a precursor for definitive operative resection
  - Avoid embolizing draining veins
    - Restricting venous outflow increases hemorrhage risk
  - Proximal embolization → collateral development → treacherous open surgical resection
Case 2

- 32 yo male with no PMH presented with seizure. Imaging revealed R temporal AVM being fed by the MCA with superficial drainage.
Embolization of M4 pedicle and Anterior Temporal pedicle resulted in 95% treatment of AVM.
- Craniotomy for complete excision of remaining AVM was performed.
- Intraoperatively, lesions embolized with n-BCA exhibit a harder, less compliant mass in contrast to lesions embolized with Onyx, which is a softer agent.
Treatment Objectives

- Embolization as a precursor for radiosurgery
  
  Goals:
  
  - Decrease target size of AVM
    - Allows higher dose of radiation to smaller volume
  
  - Reduce weakness in AVM angioarchitecture by eliminating intranidal/venous aneurysms
    - Reduces hemorrhage risk in latency period
  
  - Flow reduction alone without reduction in AVM volume does not improve radiosurgical success
Case 3

- 40 x 40 mm L parietal AVM fed by L MCA and PCA
Staged embolization over four sessions with n-BCA enabled reduction of AVM volume prior to radiosurgery. Patient now undergoing LINAC treatment for residual AVM.
Note residual AVM with diffuse pattern and persistence of early venous drainage
Treatment Objectives

- Embolization as palliation for progressive debilitating symptoms
  - Alternative for large, non-resectable AVMs
  - Progressive neurologic deficits secondary to arterial steal
  - Medically intractible seizures
  - Venous hypertension causing HA or local mass effect from engorged veins

- Target embolization of high-risk lesions
  - Associated aneurysms
  - Increased pressure in veins that have outflow restriction

- Rapidly forming collaterals reduces long-term effectiveness
Complications

- Hemorrhage/Edema
  - Arterial perforation, intranidal aneurysm rupture, draining vein occlusion
  - Occlusive Hyperemia—passive engorgement of vessels and arterial stagnation in adjacent brain following obliteration of AVM resulting in edema/hemorrhage
  - Normal Perfusion Pressure Breakthrough Theory—loss of autoregulation in surrounding ischemic tissue following embolization, resulting in disruption of capillary beds
  - Mural necrosis induced by embolic material
Complications

- **Treatment of Hemorrhage**
  - Protamine for reversal of anticoagulation

- **Treatment of Edema**
  - Steroids
Complications

- **Ischemia**
  - Inadvertent embolization of normal blood vessels
  - Thrombotic emboli
  - Retention of microcatheter

- **Treatment**
  - Deliberate hypertension
  - Platelet glycoprotein IIb/IIIa inhibitors
Morbidity and Mortality

- 10% morbidity regarding temporary neurological deficit
- 8% morbidity regarding permanent deficit
- ~1% mortality
- Complications tend to occur in higher grade AVMs
Risk of Embolization by SM Grade—Kim, et al Neurosurgery 2006

- Retrospective review of 153 patients, 508 vessels, 203 sessions
- Age, sex, AVM grade, location of lesion, number and location of embolized arteries, and number of embolization sessions reviewed with respect to neurologic/vascular complications
- Number of branches embolized was only variable related to neurologic deficit (p=0.017)
Immediate/Long term neurologic deficit

- Selection bias: most II-III not usually embolized; represent more challenging subset of lesions requiring multimodality tx
- Number of AVM per grade was too small for meaningful analysis

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<th>Spetzler-Martin Grade</th>
<th>Immediate neurologic deficit (p=0.103)</th>
<th>Follow-up neurologic deficit</th>
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Conclusion

- Pre-operative evaluation
  - Noninvasive/Invasive Imaging
  - Anesthetic/Perioperative Considerations
  - Endovascular Technique
  - Embolization Materials
  - Treatment Objectives of Endovascular Approach
  - Outcomes/Complications
  - Future
Bibliography


