

# Chapter 440: Subarachnoid Hemorrhage

Chapter 440 | Part 13: Neurologic Disorders | Part 13 – Neurologic Disorders | DETAILED EDITION

## KEY CLINICAL POINTS

1. Thunderclap headache is the hallmark of aneurysmal rupture; sudden onset is the most important characteristic.
2. Noncontrast CT within 72 h visualizes blood in >95% of cases; lumbar puncture is indicated if CT is negative.
3. Nimodipine (60 mg PO every 4 h) improves outcomes by preventing ischemic injury rather than reducing vasospasm risk.
4. ISAT trial showed 23% relative reduction in death/dependence at 1 year with endovascular coiling vs surgery.
5. Rebleeding risk is ~20% in first 2 weeks, 30% in first month, and ~3% per year if aneurysm not obliterated.
6. Free-water restriction is contraindicated in SAH due to cerebral salt wasting syndrome risk.
7. Modified Fisher Grade 4 (thick blood with intraventricular blood) carries 40% risk of symptomatic vasospasm.
8. Unruptured aneurysms <7 mm have 0% rupture risk over 5 years; <3 mm rarely bleed.
9. Sentinel bleeds (small leaks) should raise suspicion of imminent major hemorrhage.
10. Developmental venous anomalies should be ignored if found incidentally as they are functional channels.

## FIGURES IN THIS CHAPTER

1. Subarachnoid hemorrhage
2. Vasospasm of the right middle cerebral...
3. View of the major blood vessels...

## 1. DEFINITION & OVERVIEW

Subarachnoid hemorrhage (SAH) renders the brain critically ill from both primary and secondary brain insults. Excluding head trauma, the most common cause of SAH is rupture of a saccular aneurysm. Other causes include bleeding from a vascular malformation (arteriovenous malformation or dural arteriovenous fistula) and extension into the subarachnoid space from a primary intracerebral hemorrhage. Some idiopathic SAHs are localized to the perimesencephalic cisterns and are benign; they probably have a venous or capillary source, and angiography is unrevealing.

### 1.1 Vascular Malformations

- Arteriovenous Malformations (AVMs)
  - Blood from a ruptured AVM is usually not deposited in the basal cisterns.

- Symptomatic cerebral vasospasm is rare.
- Risk of AVM rupture is strongly influenced by a history of prior rupture.
- Unruptured AVMs have a hemorrhage rate of ~2–4% per year.
- Previously ruptured AVMs may have a rate as high as 17% per year, at least for the first year.
- Hemorrhages may be massive, leading to death, or may be as small as 1 cm in diameter, leading to minor focal symptoms or no deficit.
- AVM may steal blood away from adjacent normal brain tissue or increase venous pressure significantly to produce venous ischemia locally and in remote areas of the brain.
- Large AVMs in the territory of the middle cerebral artery are seen most often.
- Large AVMs of the anterior circulation may be associated with a systolic and diastolic bruit (sometimes self-audible) over the eye, forehead, or neck and a bounding carotid pulse.
- Headache at the onset of AVM rupture is generally not as explosive as with aneurysmal rupture.
- MRI is better than CT for diagnosis, although noncontrast CT scanning sometimes detects calcification of the AVM and contrast may demonstrate the abnormal blood vessels.
- Once identified, conventional x-ray angiography is the gold standard for evaluating the precise anatomy of the AVM.
- Surgical treatment of AVMs presenting with hemorrhage, often done in conjunction with preoperative embolization to reduce operative bleeding, is usually indicated for accessible lesions.
- Stereotactic radiosurgery can produce a slow sclerosis of the AVM over 2–3 years.
- Angiographic features predicting future bleeding risk:
  - Paradoxically, smaller lesions seem to have a higher hemorrhage rate.
  - Presence of deep venous drainage, venous outflow stenosis, and intranidal aneurysms may increase rupture risk.
- ARUBA trial randomized patients to medical management versus intervention (surgery, endovascular embolization, combination embolization and surgery, or gamma-knife).
  - Trial stopped prematurely for harm.
  - Medical arm achieved combined endpoint of death or symptomatic stroke in 10% of patients compared to 31% in the intervention group at a mean follow-up time of 33 months.
  - This finding argues against routine intervention for patients presenting without hemorrhage.
- Developmental Venous Anomalies
  - Result of development of anomalous cerebral, cerebellar, or brainstem venous drainage.
  - Unlike AVMs, are functional venous channels.
  - Little clinical significance and should be ignored if found incidentally on brain imaging studies.
  - Surgical resection may result in venous infarction and hemorrhage.
  - May be associated with cavernous malformations, which do carry some bleeding risk.
- Capillary Telangiectasias
  - True capillary malformations that often form extensive vascular networks through an otherwise normal brain structure.
  - Pons and deep cerebral white matter are typical locations.
  - Can be seen in patients with hereditary hemorrhagic telangiectasia (Osler-Rendu-Weber) syndrome.
  - If bleeding does occur, it rarely produces mass effect or significant symptoms.
  - No treatment options exist.
- Dural Arteriovenous Fistulas
  - Acquired connections usually from a dural artery to a dural sinus.
  - Patients may complain of a pulse-synchronous cephalic bruit ("pulsatile tinnitus") and headache.
  - Depending on the magnitude of the shunt, venous pressures may rise high enough to cause cortical ischemia or venous hypertension and hemorrhage, particularly SAH.
  - Surgical and endovascular techniques are usually curative.

- May form because of trauma, but most are idiopathic.
- Association between fistulas and dural sinus thrombosis.
- Fistulas have been observed to appear months to years following venous sinus thrombosis, suggesting that angiogenesis factors elaborated from the thrombotic process may cause these anomalous connections to form.
- Alternatively, dural arteriovenous fistulas can produce venous sinus occlusion over time, perhaps from the high pressure and high flow through a venous structure.
- Cavernous Angiomas (Cavernous Malformations)
  - Tufts of capillary sinusoids that form within the deep hemispheric white matter and brainstem with no normal intervening neural structures.
  - Pathogenesis is unclear.
  - Most cavernous angiomas are congenital, but they may occur during life as well.
  - Familial cavernous angiomas have been mapped to several different genes: KRIT1, CCM2, and PDCD10.
  - Both KRIT1 and CCM2 have roles in blood vessel formation, whereas PDCD10 is an apoptotic gene.
  - Typically <1 cm in diameter and are often associated with a venous anomaly.
  - Bleeding is usually of small volume, causing slight mass effect only.
  - Bleeding risk for single cavernous malformations is 0.7–1.5% per year and may be higher for patients with prior clinical hemorrhage or multiple malformations.
  - Seizures may occur if the malformation is located near the cerebral cortex.
  - Surgical resection eliminates bleeding risk and may reduce seizure risk but is usually reserved for those malformations that form near the brain surface in patients with prior clinical episodes of bleeding or with medically refractory seizures.
  - Stereotactic radiosurgery has been considered as a secondary treatment, but risks may outweigh benefits.
  - Retrospective data show that intracranial hemorrhage from cavernous malformations is likely not increased with administration of antiplatelet and anticoagulant medications prescribed for other medical conditions.

## 2. EPIDEMIOLOGY

- Autopsy and angiography studies have found that ~2% of adults harbor intracranial aneurysms, for a prevalence of 4 million persons in the United States.
- The incidence of SAH from aneurysmal rupture is estimated at between 6 and 11 per 100,000 person-years, resulting in 25,000–30,000 cases annually in the United States.
- There is a 1.3 relative risk in women.
- Although most affected patients are under age 55, there is also an increasing incidence with age.
- The overall mortality rate for aneurysmal SAH is ~35%, with approximately one-third of patients dying immediately and prior to hospital admission.
- Of those who survive, more than half are left with clinically significant neurologic deficits because of the initial hemorrhage, delayed cerebral ischemia, or hydrocephalus.

## 3. ETIOLOGY & PATHOPHYSIOLOGY

- Saccular aneurysms occur at the bifurcations of the large- to medium-sized intracranial arteries; rupture is into the subarachnoid space in the basal cisterns and sometimes into the parenchyma of the adjacent brain.
- Approximately 89% of aneurysms occur in the anterior circulation, particularly on the circle of Willis.
- About 20% of patients have multiple aneurysms, many at mirror sites bilaterally.

- As an aneurysm develops, it typically forms a neck with a dome. The length of the neck and the size of the dome vary greatly and are important factors in planning neurosurgical obliteration or endovascular embolization.
- The arterial internal elastic lamina disappears at the base of the neck.
- The media thins, and connective tissue replaces smooth-muscle cells.
- At the site of rupture (most often the dome), the wall thins, and the tear that allows bleeding is often  $\leq 0.5$  mm long.
- Fusiform aneurysms, where the locations of inflow and outflow are different, typically occur in the basilar artery and are very challenging to treat.
- Pathophysiology of Rupture
  - Rupture is into the subarachnoid space in the basal cisterns and sometimes into the parenchyma of the adjacent brain.
  - The intracranial pressure (ICP) suddenly rises at the moment of aneurysmal rupture with a major SAH.
  - This may account for the sudden transient loss of consciousness that occurs in nearly half of patients.
  - Sudden loss of consciousness may be preceded by a brief moment of excruciating headache, but most patients first complain of headache upon regaining consciousness.
  - In 10% of cases, aneurysmal bleeding is severe enough to cause loss of consciousness for several days.
  - In  $\sim 45\%$  of cases, severe headache associated with exertion is the presenting complaint.
  - The patient often calls the headache "the worst headache of my life"; however, the most important characteristic is sudden onset.
  - Occasionally, these ruptures may present as headache of only moderate intensity or as a change in the patient's usual headache pattern.
  - The headache is usually generalized, often with neck stiffness, and vomiting is common.
  - Although sudden headache in the absence of focal neurologic symptoms is the hallmark of aneurysmal rupture, focal neurologic deficits may occur.
  - Anterior communicating artery or MCA bifurcation aneurysms may rupture into the adjacent brain or subdural space and form a hematoma large enough to produce mass effect.
  - The deficits that result can include hemiparesis, aphasia, and mental slowness (abulia).
  - Occasionally, prodromal symptoms suggest the location of a progressively enlarging unruptured aneurysm.
  - A third cranial nerve palsy, particularly when associated with pupillary dilation, loss of ipsilateral (but retained contralateral) light reflex, and focal pain above or behind the eye, may occur with an expanding aneurysm at the junction of the posterior communicating artery and the internal carotid artery.
  - A sixth nerve palsy may indicate an aneurysm in the cavernous sinus.
  - Visual field defects can occur with an expanding supraclinoid carotid or anterior cerebral artery (ACA) aneurysm.
  - Occipital and posterior cervical pain may signal a posterior inferior cerebellar artery or anterior inferior cerebellar artery aneurysm.
  - Pain in or behind the eye and in the low temple can occur with an expanding MCA aneurysm.

## 4. CLINICAL FEATURES

- Most unruptured intracranial aneurysms are completely asymptomatic.
- Symptoms are usually due to rupture.
- The clinical syndrome often manifests as a decline in mental status and worsening headache.
- Vasospasm of the large arteries can be detected reliably with conventional x-ray angiography, but this procedure is invasive and carries the risk of stroke and other complications.

- Transcutaneous Doppler ultrasound is based on the principle that the velocity of blood flow within an artery will rise as the lumen diameter is narrowed.
- By directing the probe along the MCA and proximal ACA, carotid terminus, and vertebral and basilar arteries on a daily or every-other-day basis, vasospasm can be reliably detected and treatments initiated to prevent cerebral ischemia.
- Computed tomography (CT) angiography is another method that can detect vasospasm.
- The addition of CT perfusion imaging may help identify reversible ischemic deficits.
- In high-grade patients, invasive neuro-monitoring techniques can also be considered.
- Sentinel Bleeds
  - Aneurysms can undergo small ruptures and leaks of blood into the subarachnoid space, so-called sentinel bleeds.
  - Sudden unexplained headache at any location should raise suspicion of SAH and be investigated because a major hemorrhage may be imminent.
- Delayed Neurologic Deficits
  - There are four major causes of delayed neurologic deficits:

### 1. Rerupture

- The incidence of rerupture of an untreated aneurysm in the first month following SAH is ~30%, with the peak in the first 7 days.
- Rerupture is associated with a 50% mortality rate and poor outcome.
- Early treatment eliminates this risk.

### 2. Hydrocephalus

- Acute hydrocephalus can cause stupor and coma.
- Can be mitigated by placement of an external ventricular drain.
- More often, subacute hydrocephalus may develop over a few days or weeks and cause progressive drowsiness or slowed mentation with incontinence.
- Hydrocephalus may clear spontaneously, require temporary ventricular drainage, or in some cases require placement of a ventriculoperitoneal shunt.
- Chronic hydrocephalus may develop weeks to months after SAH and manifest as gait difficulty, incontinence, or impaired mentation.
- Subtle signs may be a lack of initiative in conversation or a failure to recover independence.

### 3. Delayed Cerebral Ischemia

- Vasospasm is the narrowing of the arteries at the base of the brain following SAH and has been associated with delayed cerebral ischemia and infarction.
- Delayed cerebral ischemia occurs in ~30% of patients and is the major cause of delayed morbidity and death.
- Signs first appear 4–14 days after the hemorrhage, most often at 7 days.
- While therapies can be targeted for vasospasm, there are other complex mechanisms associated with delayed cerebral ischemia and progression to infarction independent of vasospasm alone.
- Narrowing of the arteries causing vasospasm and thickening of the vessel wall is believed to result from direct effects of clotted blood and its breakdown products on the arteries within the subarachnoid space.
- In general, the more blood that surrounds the arteries, the greater is the chance of symptomatic vasospasm.
- Focal narrowing of major arteries produces symptoms referable to the appropriate vascular territory.
- All of these focal symptoms may present abruptly, fluctuate, or develop over a few days.

### 4. Hyponatremia

- Hyponatremia may be profound and can develop quickly in the first 2 weeks following SAH.

- There is both natriuresis and volume depletion with SAH, so that patients become both hyponatremic and hypovolemic.
- Both atrial natriuretic peptide and brain natriuretic peptide have a role in producing this "cerebral salt-wasting syndrome."
- Typically, it clears over the course of 1–2 weeks.
- In the setting of SAH, should not be treated with free-water restriction as this may increase the risk of stroke.

## 5. DIFFERENTIAL DIAGNOSIS

- Thunderclap headache is a variant of migraine that simulates an SAH.
- Before concluding that a patient with sudden, severe headache has thunderclap migraine, a definitive workup for aneurysm or other intracranial pathology is required.
- Idiopathic SAHs are localized to the perimesencephalic cisterns and are benign; they probably have a venous or capillary source, and angiography is unrevealing.

## 6. INVESTIGATIONS & DIAGNOSIS

- **Laboratory Evaluation and Imaging**
  - The hallmark of aneurysmal rupture is blood in the CSF.
  - More than 95% of cases have enough blood to be visualized on a high-quality noncontrast CT scan obtained within 72 h.
  - If the scan fails to establish the diagnosis of SAH and no mass lesion or obstructive hydrocephalus is found, a lumbar puncture should be performed to establish the presence of subarachnoid blood.
  - Lysis of the red blood cells and subsequent conversion of hemoglobin to bilirubin stains the spinal fluid yellow within 6–12 h.
  - This xanthochromic spinal fluid peaks in intensity at 48 h and lasts for 1–4 weeks, depending on the amount of subarachnoid blood present.
  - The extent and location of subarachnoid blood on a noncontrast CT scan help locate the underlying aneurysm, identify the cause of any neurologic deficit, and predict the occurrence of vasospasm.
  - The likelihood of symptomatic vasospasm in the MCA and ACA can be predicted based on the size and location of clotted blood.
  - CT scans less reliably predict vasospasm in the vertebral, basilar, or posterior cerebral arteries.
  - Lumbar puncture prior to an imaging procedure is indicated only if a CT scan is not available at the time of the suspected SAH.
  - Once the diagnosis of hemorrhage from a ruptured saccular aneurysm is confirmed, four-vessel conventional x-ray angiography (both carotids and both vertebrals) is generally performed to localize and define the anatomic details of the aneurysm and to determine if other unruptured aneurysms exist.
  - The ruptured aneurysm can be treated using endovascular techniques at the time of the initial angiogram to expedite treatment and minimize the number of invasive procedures.
  - CT angiography is an alternative method for locating the aneurysm and may be sufficient for planning definitive therapy.
  - Close monitoring (daily or twice daily) of electrolytes is important because hyponatremia can occur precipitously during the first 2 weeks following SAH.
  - The electrocardiogram (ECG) frequently shows ST-segment and T-wave changes similar to those associated with cardiac ischemia.
  - A prolonged QRS complex, increased QT interval, and prominent "peaked" or deeply inverted symmetric T waves are usually secondary to the intracranial hemorrhage.

- Structural myocardial lesions produced by circulating catecholamines and excessive discharge of sympathetic neurons may occur after SAH, causing these ECG changes and a reversible cardiomyopathy sufficient to cause shock.
- Echocardiography often reveals a pattern of regional wall motion abnormalities that follow the distribution of sympathetic nerves rather than the major coronary arteries, with relative sparing of the ventricular wall apex.
- The sympathetic nerves themselves appear to be injured by direct toxicity from the intracranial hemorrhage.
- An asymptomatic troponin elevation is common.
- While arrhythmias can occur after SAH, serious ventricular dysrhythmias occurring in-hospital are unusual.

## 6.1 Grading Scales

- The initial clinical manifestations of SAH can be graded using the Hunt-Hess or World Federation of Neurosurgical Societies classification schemes.
- For ruptured aneurysms, prognosis for a good outcome falls as the grade increases.
- For example, it is unusual for a Hunt-Hess grade 1 patient to die if the aneurysm is treated, but the mortality rate for grade 4 and 5 patients may be as high as 60%.
- The extent and location of subarachnoid blood on a noncontrast CT scan help locate the underlying aneurysm, identify the cause of any neurologic deficit, and predict the occurrence of vasospasm.

**Table 1 Table 440-1 Grading Scales for Subarachnoid Hemorrhage**

GRADE	HUNT-HESS SCALE	WORLD FEDERATION OF NEUROSURGICAL SOCIETIES (WFNS) SCALE
1	Asymptomatic, or minimal headache and slight nuchal rigidity. Normal mental status, no cranial nerve or motor findings	GCSa score 15, no motor deficits
2	Moderate to severe headache, nuchal rigidity, normal mental status and motor function, may have cranial nerve deficit	GCS score 13–14, no motor deficits
3	Somnolent, confused, may have cranial nerve or mild motor deficit	GCS score 13–14, with motor deficits
4	Stupor, moderate to severe motor deficit, may have intermittent reflex posturing	GCS score 7–12, with or without motor deficits
5	Coma, reflex posturing or flaccid without motor deficits	GCS score 3–6, with or without motor deficits

**Table 2 Table 440-2 Modified Fisher Grading System for Prediction of Vasospasm Risk**

GRADE	CT SCAN FINDINGS	RISK OF SYMPTOMATIC VASOSPASM
0	No subarachnoid or intraventricular blood	0%
1	Focal or diffuse thin subarachnoid blood without intraventricular blood	24%

GRADE	CT SCAN FINDINGS	RISK OF SYMPTOMATIC VASOSPASM
2	Focal or diffuse thin subarachnoid blood with intraventricular blood	33%
3	Focal or diffuse thick subarachnoid blood without intraventricular blood	33%
4	Focal or diffuse thick subarachnoid blood with intraventricular blood	40%

## 7. MANAGEMENT & TREATMENT

- Early aneurysm repair prevents rerupture and allows the safe application of techniques to improve blood flow (e.g., induced hypertension) should vasospasm and delayed cerebral ischemia develop.
- At many centers, definitive repair is carried out within 24 h of the bleed in all patients who are stable enough to tolerate the procedure.
- Prior to definitive treatment of the ruptured aneurysm, care is required to maintain adequate cerebral perfusion pressure while avoiding excessive elevation of arterial pressure.
- If the patient is alert, it is reasonable to lower the systolic blood pressure to below 160 mmHg using agents such as nicardipine, clevidipine, or labetalol to limit blood pressure variability.
- If the patient has a depressed level of consciousness, ICP should be measured and the cerebral perfusion pressure targeted to 60–70 mmHg.
- If headache or neck pain is severe, mild sedation and analgesia are prescribed.
- Extreme sedation is avoided if possible because it can obscure the ability to clinically detect changes in neurologic status.
- Goal-directed therapy to target euvolemia is recommended, while avoiding hypervolemia, which has been associated with a greater risk for complications.
- Seizures are uncommon at the onset of aneurysmal rupture, but in patients who present with seizures, treatment with a 7-day course of an anticonvulsant such as levetiracetam is reasonable.
- The quivering, jerking, and extensor posturing that often accompany loss of consciousness with SAH are probably related to the sharp rise in ICP rather than seizures.
- Monitoring with electroencephalogram (EEG) can help detect seizures in patients with poor mental status or fluctuating exam findings.
- Anticonvulsants are sometimes administered as prophylactic therapy in high-risk patients, but if used, the treatment course should also not exceed >7 days.
- Phenytoin should be avoided because of its association with increased morbidity and mortality in this setting.
- Glucocorticoids may reduce the headache and neckache caused by the irritative effect of the subarachnoid blood; however, there is no good evidence that steroids reduce cerebral edema, are neuroprotective, or reduce vascular injury, and their routine use therefore is not recommended.
- Antifibrinolytic agents are not routinely prescribed but have been considered in patients in whom aneurysm repair cannot proceed immediately.
- They are associated with a reduced incidence of aneurysmal rerupture but may also increase the risk of delayed cerebral ischemia and deep-vein thrombosis (DVT).
- More recent studies showed no improvement in functional outcomes, and use of these agents is not currently recommended.

- Delayed cerebral ischemia remains the leading cause of morbidity and mortality following aneurysmal SAH in patients who survive the initial hemorrhage.
- Treatment with the calcium channel antagonist nimodipine (60 mg PO every 4 h) has been shown to improve outcomes, perhaps by preventing ischemic injury rather than reducing the risk of vasospasm.
- Nimodipine can cause significant hypotension in some patients, which may worsen cerebral ischemia in patients with vasospasm.
- Symptomatic cerebral vasospasm can also be treated by increasing the cerebral perfusion pressure by raising mean arterial pressure through plasma volume expansion and the judicious use of IV vasopressor agents, usually phenylephrine or norepinephrine.
- Increasing perfusion pressure has been associated with clinical improvement in many patients, but high arterial pressure may also promote rebleeding in unruptured aneurysms.
- Treatment with induced hypertension in symptomatic patients requires close monitoring of arterial pressures.
- Prophylactic use of induced hypertension is not recommended, as it is associated with worse outcomes.
- Euvolemia should be targeted as significant hypervolemia may lead to cardiopulmonary complications.
- Hypovolemia should be strictly avoided.
- If delayed cerebral ischemia due to vasospasm persists despite optimal medical therapy, endovascular rescue therapies with intra-arterial vasodilators and percutaneous transluminal angioplasty can be considered.
- Vasodilatation by direct angioplasty appears to be permanent, allowing hypertensive therapy to be tapered sooner.
- In contrast, the pharmacologic vasodilators (verapamil and nicardipine) do not last more than about 24 h, and therefore, multiple treatments may be required until the subarachnoid blood is reabsorbed.
- Newer therapies including milrinone, neural ganglia blocks, antithrombotic agents, and intrathecal and cisternal agents are currently under investigation.
- Severe cerebral edema in patients with infarction from vasospasm may increase the ICP to levels that reduce cerebral perfusion pressure.
- Treatment may include cerebrospinal fluid (CSF) drainage, mannitol, or hypertonic saline; for intractable cases, hemicraniectomy, deep sedation, paralysis, and moderate hypothermia may be considered.
- Free-water restriction is contraindicated in patients with SAH at risk for delayed cerebral ischemia because hypovolemia and hypotension may occur and precipitate cerebral ischemia.
- Many patients continue to experience a decline in serum sodium due to cerebral salt wasting despite receiving parenteral fluids containing normal saline.
- Frequently, supplemental oral salt coupled with normal saline will mitigate hyponatremia, but often patients also require intravenous hypertonic (3%) saline.
- Care must be taken not to correct serum sodium too quickly in patients with marked hyponatremia of several days' duration, as the osmotic demyelination syndrome may occur.
- All patients should have pneumatic compression stockings applied to prevent pulmonary emboli.
- Unfractionated heparin and low-molecular-weight heparoids administered subcutaneously for DVT prophylaxis can be initiated within 1–2 days following endovascular treatment or craniotomy with surgical clipping; this approach is more effective than use of pneumatic compression stockings alone.
- Treatment of pulmonary emboli depends on whether the aneurysm has been treated and whether or not the patient has had a craniotomy.
- Continuous systemic anticoagulation with heparin is contraindicated in patients with ruptured and untreated aneurysms.

- It is a relative contraindication following craniotomy for several days, and it may delay thrombosis of a coiled aneurysm.
- If DVT or pulmonary emboli occur within the first days following craniotomy, use of an inferior vena cava filter may be considered to prevent additional emboli, whereas systemic anticoagulation with heparin is preferred following successful endovascular treatment.
- In patients who survive their acute hospitalization, follow-up care is important to address the high prevalence of cognitive and behavioral deficits that greatly impact quality of life.
- Efficient recognition and treatment of these disorders can improve both short-term and long-term outcomes.
- In addition, some patients require ongoing follow-up to manage unruptured aneurysms that may require further care.

## 7.1 Surgical vs. Endovascular Treatment

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- An aneurysm can be "clipped" by a neurosurgeon or "coiled" by an endovascular surgeon.
- Surgical repair involves placing a metal clip across the aneurysm neck, thereby immediately eliminating the risk of rebleeding.
- This approach requires craniotomy and brain retraction, which is associated with neurologic morbidity.
- Endovascular techniques involve placing coils, or other embolic material, within the aneurysm via a catheter that is passed from the femoral or radial artery.
- The aneurysm is packed tightly to enhance thrombosis and over time is walled off from the circulation.
- There have been two prospective randomized trials of surgery versus endovascular treatment for ruptured aneurysms:
  - The first was the International Subarachnoid Aneurysm Trial (ISAT), which was terminated early when 24% of patients treated with endovascular therapy were dead or dependent at 1 year compared to 31% treated with surgery, a significant 23% relative reduction.
  - After 5 years, the risk of death was still lower in the coiling group, although the proportion of survivors who were independent was the same in both groups.
  - The risk of rebleeding was generally low, but was more common in the coiling group.
  - These results favoring coiling at 1 year were confirmed in a second trial, although the differences in functional outcome of survivors were no longer significant at 3 years.
  - Because some aneurysms have a morphology that is not amenable to endovascular treatment, surgery remains an important treatment option, especially in cases where evacuation of a parenchymal hematoma could be beneficial.
  - Newer endovascular devices and techniques using balloon-assisted coiling or placement of flow-diverting stents are increasing the types of aneurysms amenable to endovascular intervention.
  - Centers that combine both endovascular and neurosurgical expertise likely offer the best outcomes for patients, and transfer to centers that specialize in aneurysm treatment are associated with improved outcomes and lower mortality rates.

## 7.2 Medical Management Priorities

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- The early medical management of SAH focuses on protecting the airway, managing blood pressure before and after repair of the aneurysm, preventing rebleeding prior to the intervention, and treating hydrocephalus.
- Subsequent management is focused on preventing late neurologic injury, including managing vasospasm and delayed cerebral ischemia, treating hyponatremia, limiting secondary brain insults from medical comorbidities, and preventing pulmonary emboli.
- Intracranial hypertension following aneurysmal rupture occurs secondary to subarachnoid blood, parenchymal hematoma, acute hydrocephalus, and/or loss of vascular autoregulation.

- Patients who are stuporous should undergo emergent ventriculostomy to measure and treat high ICP in order to prevent cerebral herniation and ischemia.
- Medical therapies designed to combat raised ICP (e.g., osmotic therapy and sedation) can also be used as needed.
- Drainage of CSF via a lumbar route has been shown to decrease the rate of delayed cerebral injury, vasospasm, and mortality but confounds measurement of true ICP.

## 8. PROGNOSIS & COMPLICATIONS

- The overall mortality rate for aneurysmal SAH is ~35%, with approximately one-third of patients dying immediately and prior to hospital admission.
- Of those who survive, more than half are left with clinically significant neurologic deficits because of the initial hemorrhage, delayed cerebral ischemia, or hydrocephalus.
- If the patient survives but the aneurysm is not obliterated, the rate of rebleeding is ~20% in the first 2 weeks, 30% in the first month, and ~3% per year afterward.
- For ruptured aneurysms, prognosis for a good outcome falls as the grade increases.
- For example, it is unusual for a Hunt-Hess grade 1 patient to die if the aneurysm is treated, but the mortality rate for grade 4 and 5 patients may be as high as 60%.
- Delayed cerebral ischemia remains the leading cause of morbidity and mortality following aneurysmal SAH in patients who survive the initial hemorrhage.
- Rerupture is associated with a 50% mortality rate and poor outcome.
- Chronic hydrocephalus may develop weeks to months after SAH and manifest as gait difficulty, incontinence, or impaired mentation.
- Subtle signs may be a lack of initiative in conversation or a failure to recover independence.
- In patients who survive their acute hospitalization, follow-up care is important to address the high prevalence of cognitive and behavioral deficits that greatly impact quality of life.
- Efficient recognition and treatment of these disorders can improve both short-term and long-term outcomes.
- In addition, some patients require ongoing follow-up to manage unruptured aneurysms that may require further care.

## 9. SPECIAL CONSIDERATIONS

- Unruptured, asymptomatic aneurysms are much less dangerous than recently ruptured ones.
- A large international observational study found that the annual risk of rupture for unruptured aneurysms <7 mm in size was 0% over 5 years.
- However, subsequent studies from Japan and Finland found that the majority of ruptured aneurysms were <6 mm in size.
- Aneurysms of <3 mm in size rarely, if ever, bleed.
- As the size of an aneurysm increases, so does the risk for rupture, but growth is not linear and appears to occur in phases, making surveillance for growing aneurysms problematic.
- The location of an unruptured aneurysm is also important in assessment, as basilar bifurcation and origin posterior communicating artery aneurysms appear to have a higher risk for rupture than other sites.
- Because of their longer length of exposure to and resultant risk of rupture, younger patients with aneurysms >10 mm in size may benefit from prophylactic treatment.

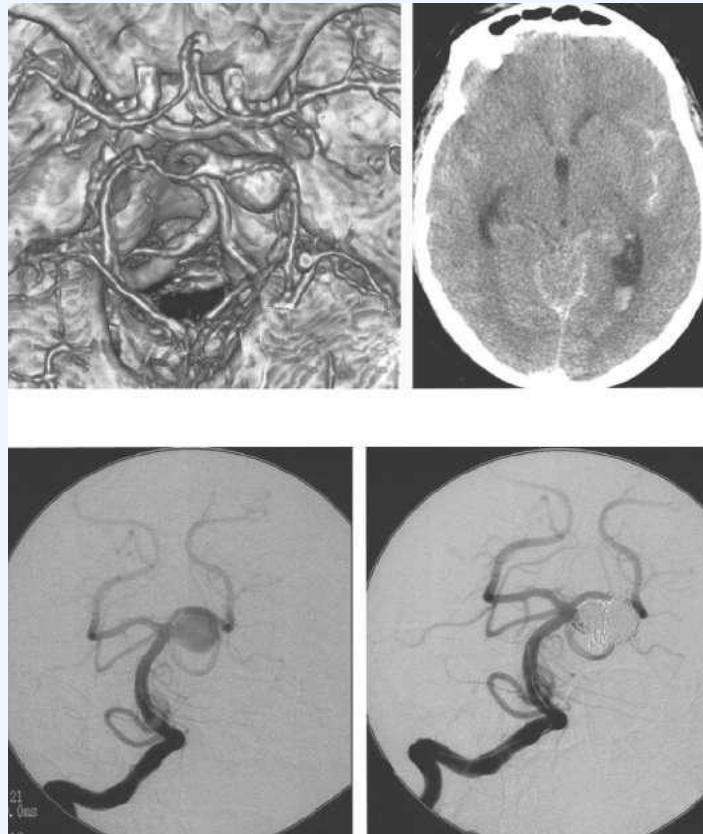
- As with the treatment of asymptomatic carotid stenosis, this risk-benefit ratio strongly depends on the rate of procedural complications.
- Giant aneurysms, those >25 mm in diameter, occur at the same sites as small aneurysms, and account for 5% of cases.
- The three most common locations are the terminal internal carotid artery, middle cerebral artery (MCA) bifurcation, and top of the basilar artery.
- Their risk of rupture is ~8–10% annually after identification and may remain high indefinitely.
- They often cause symptoms by compressing the adjacent brain or cranial nerves.
- Developmental venous anomalies are the result of development of anomalous cerebral, cerebellar, or brainstem venous drainage.
- These structures, unlike AVMs, are functional venous channels.
- They are of little clinical significance and should be ignored if found incidentally on brain imaging studies.
- Surgical resection of these anomalies may result in venous infarction and hemorrhage.
- Venous anomalies may be associated with cavernous malformations, which do carry some bleeding risk.
- Capillary telangiectasias are true capillary malformations that often form extensive vascular networks through an otherwise normal brain structure.
- The pons and deep cerebral white matter are typical locations, and these capillary malformations can be seen in patients with hereditary hemorrhagic telangiectasia (Osler-Rendu-Weber) syndrome.
- If bleeding does occur, it rarely produces mass effect or significant symptoms.
- No treatment options exist.
- Dural arteriovenous fistulas are acquired connections usually from a dural artery to a dural sinus.
- Patients may complain of a pulse-synchronous cephalic bruit ("pulsatile tinnitus") and headache.
- Depending on the magnitude of the shunt, venous pressures may rise high enough to cause cortical ischemia or venous hypertension and hemorrhage, particularly SAH.
- Surgical and endovascular techniques are usually curative.
- These fistulas may form because of trauma, but most are idiopathic.
- There is an association between fistulas and dural sinus thrombosis.
- Fistulas have been observed to appear months to years following venous sinus thrombosis, suggesting that angiogenesis factors elaborated from the thrombotic process may cause these anomalous connections to form.
- Alternatively, dural arteriovenous fistulas can produce venous sinus occlusion over time, perhaps from the high pressure and high flow through a venous structure.
- Cavernous angiomas (cavernous malformations) are tufts of capillary sinusoids that form within the deep hemispheric white matter and brainstem with no normal intervening neural structures.
- The pathogenesis is unclear.
- Most cavernous angiomas are congenital, but they may occur during life as well.
- Familial cavernous angiomas have been mapped to several different genes: KRIT1, CCM2, and PDCD10.
- Both KRIT1 and CCM2 have roles in blood vessel formation, whereas PDCD10 is an apoptotic gene.
- Cavernous angiomas are typically <1 cm in diameter and are often associated with a venous anomaly.
- Bleeding is usually of small volume, causing slight mass effect only.
- The bleeding risk for single cavernous malformations is 0.7–1.5% per year and may be higher for patients with prior clinical hemorrhage or multiple malformations.
- Seizures may occur if the malformation is located near the cerebral cortex.

- Surgical resection eliminates bleeding risk and may reduce seizure risk but is usually reserved for those malformations that form near the brain surface in patients with prior clinical episodes of bleeding or with medically refractory seizures.
- Stereotactic radiosurgery has been considered as a secondary treatment, but risks may outweigh benefits.
- Retrospective data show that intracranial hemorrhage from cavernous malformations is likely not increased with administration of antiplatelet and anticoagulant medications prescribed for other medical conditions.

## 10. KEY PEARLS & CLINICAL TRAPS

- Although sudden headache in the absence of focal neurologic symptoms is the hallmark of aneurysmal rupture, focal neurologic deficits may occur.
- Thunderclap headache is a variant of migraine that simulates an SAH.
- Before concluding that a patient with sudden, severe headache has thunderclap migraine, a definitive workup for aneurysm or other intracranial pathology is required.
- Free-water restriction is contraindicated in patients with SAH at risk for delayed cerebral ischemia because hypovolemia and hypotension may occur and precipitate cerebral ischemia.
- Antifibrinolytic agents are not routinely prescribed but have been considered in patients in whom aneurysm repair cannot proceed immediately. They are associated with a reduced incidence of aneurysmal rerupture but may also increase the risk of delayed cerebral ischemia and deep-vein thrombosis (DVT). More recent studies showed no improvement in functional outcomes, and use of these agents is not currently recommended.
- Glucocorticoids may reduce the headache and neckache caused by the irritative effect of the subarachnoid blood; however, there is no good evidence that steroids reduce cerebral edema, are neuroprotective, or reduce vascular injury, and their routine use therefore is not recommended.
- Developmental venous anomalies should be ignored if found incidentally as they are functional channels.
- Unruptured aneurysms <7 mm have 0% rupture risk over 5 years; <3 mm rarely bleed.

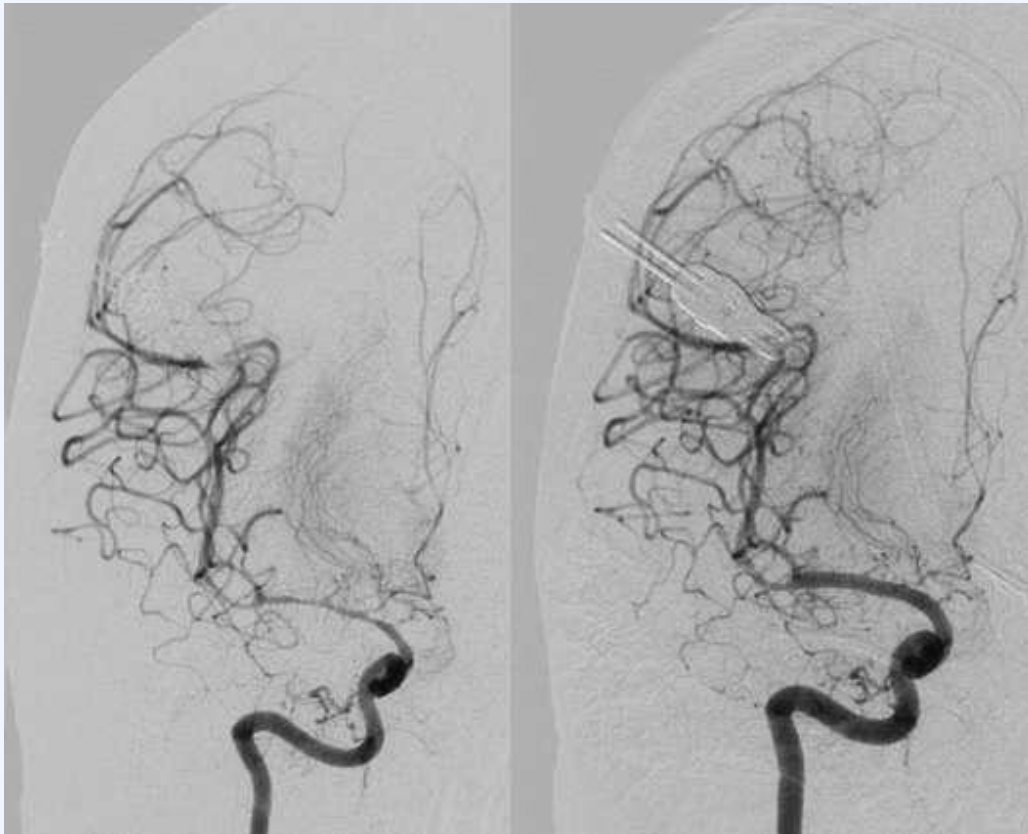
## FIGURES & ILLUSTRATIONS — FROM HARRISON'S



Harrison's 22e · Figure 1

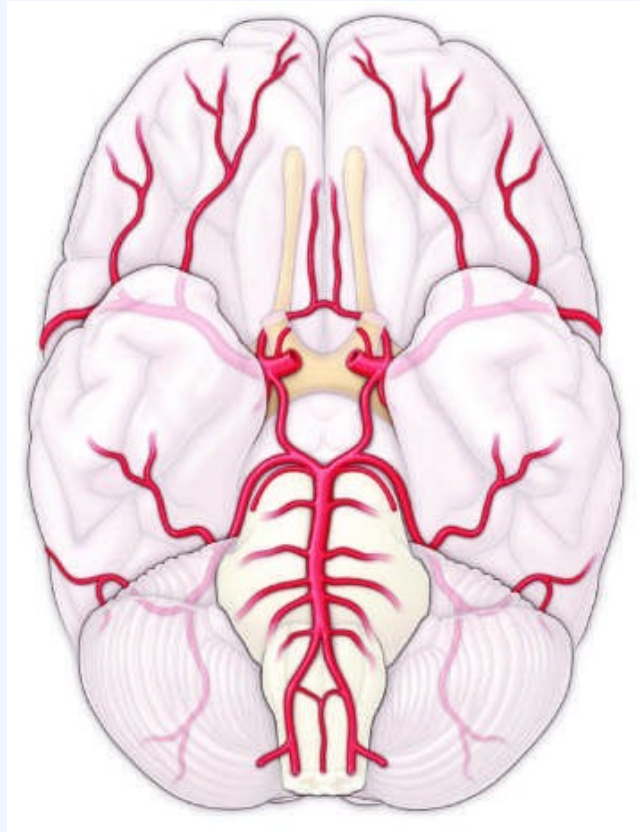
*FIGURE 440-2 Subarachnoid hemorrhage. A. Computed tomography (CT) angiography revealing an aneurysm of the left superior cerebellar artery. B. Noncontrast CT scan at the level of the third ventricle revealing subarachnoid blood (bright) in the left sylvian fissure and within the left lateral ventricle. C. Conventional anteroposterior x-ray angiogram of the right vertebral and basilar artery showing the large aneurysm. D. Conventional angiogram following coil embolization of the aneurysm, whereby the aneurysm body is filled with platinum coils delivered through a microcatheter navigated from the femoral artery into the aneurysm neck.*

*An asymptomatic troponin — Figure 440-1: View of the major blood vessels supplying the brain and common locations of saccular aneurysms, including anterior communicating, internal carotid, posterior communicating, middle cerebral, basilar terminus, superior cerebellar, anterior inferior cerebellar, and posterior inferior cerebellar arteries.*



Harrison's 22e · Figure 2

*FIGURE 440-3 Vasospasm of the right middle cerebral artery. A. Catheter angiography demonstrates significant narrowing of the right middle cerebral artery (MCA). B. Because of symptomatic delayed cerebral ischemia, soft-balloon angioplasty was used to dilate the proximal portion of the main MCA stem. — Figure 440-2: Subarachnoid hemorrhage imaging and treatment. A: CT angiography revealing an aneurysm of the left superior cerebellar artery. B: Noncontrast CT scan showing subarachnoid blood (bright) in the left sylvian fissure and within the left lateral ventricle. C: Conventional x-ray angiogram showing a large aneurysm. D: Conventional angiogram following coil embolization of the aneurysm.*



Harrison's 22e · Figure 3

*FIGURE 440-1 View of the major blood vessels supplying the brain and common of locations of saccular aneurysms: (1) Anterior communicating (12%), (2) internal carotid (30%), (3) posterior communicating (12%), (4) middle cerebral (34%), (5) basilar terminus, (6) superior cerebellar, (7) anterior inferior cerebellar, and (8) is posterior inferior cerebellar aneurysm. Locations 1–4 are considered anterior — Figure 440-3: Vasospasm of the right middle cerebral artery. A: Catheter angiography demonstrates significant narrowing. B: Soft-balloon angioplasty used to dilate the proximal portion of the main MCA stem due to symptomatic delayed cerebral ischemia.*