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Chapter 4

Aneurysmal Subarachnoid Hemorrhage

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Abstract

Aneurysmal subarachnoid hemorrhage (SAH) is a devastating neurological syndrome, which occurs at a rate of 3–25 per 100,000 population. Smoking and hypertension are the most important risk factors of subarachnoid hemorrhage. Rupture of cerebral aneurysm leads to rapid spread of blood into cerebrospinal fluid and subsequently leads to sudden increase of intracranial pressure and severe headache. Subarachnoid hemorrhage is associated with neurological (such as re-bleeding and vasospasm) and systemic (such as myocardial injury and hyponatremia) complications that are causes of high mortality and morbidity. Although patients with poor-grade subarachnoid hemorrhage are at higher risk of neurological and systemic complications, the early and aggressive management of this group of patient has decreased overall mortality by 17% in last 40 years. Early aneurysm repair, close monitoring in dedicated neurological intensive care unit, prevention, and aggressive management of medical and neurological complications are the most important strategies to improve outcome.

Keywords: albumin, aneurysmal subarachnoid hemorrhage, vasospasm, re-bleeding, hyponatremia, cardiac complication, coiling, clipping

1. Introduction

Subarachnoid hemorrhage (SAH) is a devastating disease and is associated with high mortality and poor outcomes among survivors, management by multidisciplinary team is associated with improved outcomes; however, intensive care management presents big challenge. Most

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of spontaneous SAH is due to the rupture of saccular aneurysm, the prevalence of intracranial saccular aneurysm by radiographic and autopsy series is 5%, about 20–30% of patients have several aneurysms [1].

Aneurysmal SAH (aSAH) occurs at a rate of 2–16 per 100,000 population, mostly occurring between 40 and 60 years of age; however, young children and elderly can be affected. The incidence of SAH is higher in women than men, which may be due to hormonal status. African Americans are at a higher risk of SAH than Caucasian Americans. Mortality rate is about 60% within first 6 months [2, 3].

2. Circle of Willis

The circle of Willis is an anastomotic structure. It is formed when the internal carotid artery enters the cranial cavity bilaterally and divides into the anterior cerebral artery and middle cerebral artery, and the anterior cerebral arteries are then united by an anterior communicating artery. These anastomoses form the anterior half of the circle (anterior circulation). Posteriorly, the basilar artery branches to give left and right posterior cerebral artery (posterior circulation). Posterior cerebral arteries join the internal carotid system anteriorly to complete the circle via posterior communicating arteries. **Figure 1** shows the common sites of cerebral aneurysm [4, 5].

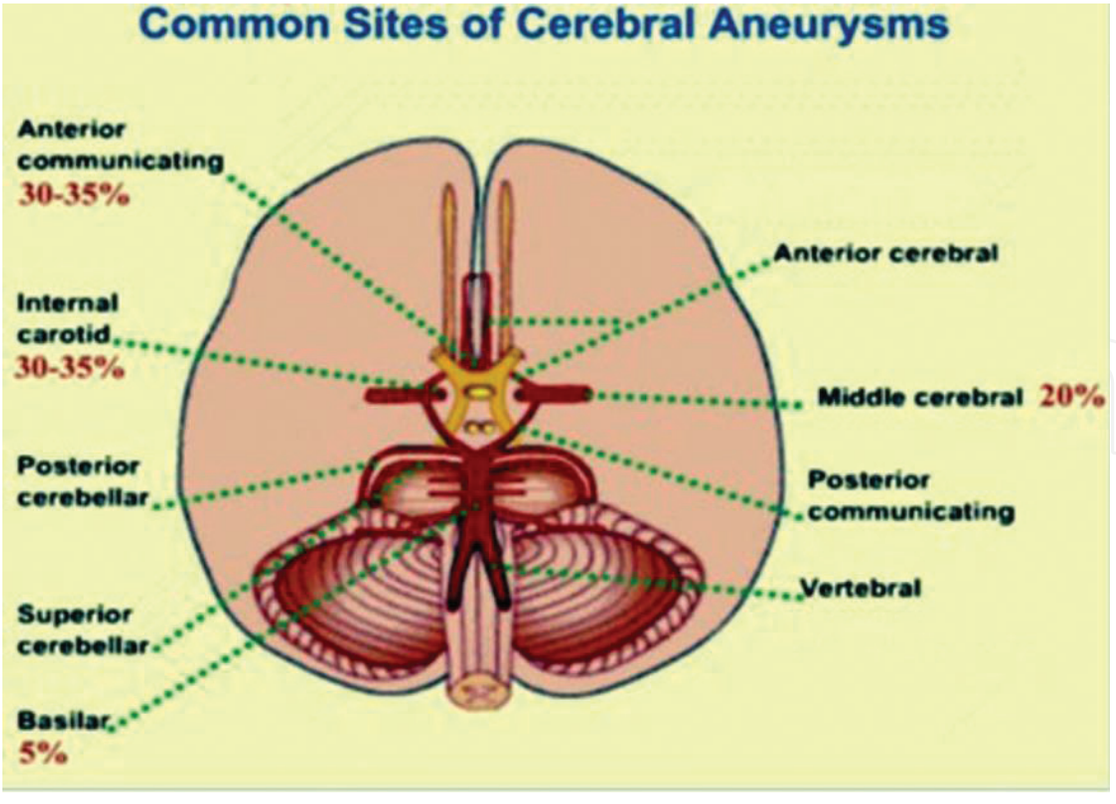

Figure 1. Common sites of cerebral aneurysm [5].

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3. Etiology

Subarachnoid hemorrhage is defined as bleeding into the space between the arachnoid and pia mater of the meninges enclosing the brain (subarachnoid space). The most common reason for spontaneous (non-traumatic) SAH is the rupture of a cerebral aneurysm (85%) [5].

In about 15% of non-traumatic SAH, no bleeding cause is identified by digital subtraction angiography (DSA). In these scenarios, differentiation between perimesencephalic and non-perimesencephalic location of the SAH is very important to determine further therapeutic approach [3].

Perimesencephalic SAH (PMSAH) is defined by the absence of an aneurysmatic bleeding and the classic presence of blood within the perimesencephalic and prepontine cisterns [3].

Computed topography angiogram (CTA) and magnetic resonance angiography (MRA) have high sensitivity of excluding aneurysmal bleedings in PMSAH.

PMSAH has less complication and better prognosis than aneurysmal SAH.

Non-perimesencephalic is SAH without bleeding source in the baseline DSA, the chance of positive findings in a follow-up angiography fluctuated between 5 and 35%, that is why DSA should be repeated not before 3 weeks after the initial bleeding if there are no other therapeutic indications [3].

Non-traumatic SAH can be caused by various other non-aneurysmatic causes (**Table 1**), and the management of these cases must be performed according to the underlying cause [3].

Disease	Example
Infectious arterial vasculitis	Mycotic (infectious) aneurysm
	Meningovascular lues
	Lyme disease
	Gnathostomiasis (Gnathostoma spinigerum)
Immune vasculitis	Primary CNS angiitis
	Polyarteritis nodosa
	Wegener's vasculitis
	Churg-Strauss syndrome
	Behçet's disease
Other cerebrovascular diseases	Arteriovenous angioma
	Dural arteriovenous fistula
	Spinal arterial aneurysm
	Intracranial arterial dissection
	Venous sinus thrombosis
	Cerebral amyloid angiopathy
	Moyamoya disease

Disease	Example
Tumor	Intracranial und intraspinal tumor
Hematology	Sickle cell anemia
Drugs	Anticoagulants and thrombolytic therapy
Substance abuse	Cocaine

Table 1. Rare causes of non-traumatic SAH [3].

4. Risk factors

Most spontaneous SAHs result from the rupture of intracranial aneurysms; therefore, risk factors for aneurysm formation overlap with risk factors for SAH.

(1) Cigarette smoking: It is associated with 11-fold increased risk of SAH. Worldwide, it is the most important preventable risk factor, which has been proved in numerous cohort (relative risk, RR, of current smoking, 2.2) and case-control studies (odds ratio, OR, 3.1); cigarette smoking also hastened aneurysm growth rate [2, 3].

(2) Hypertension: It is a major risk factor for SAH and possibly for aneurysm formation and fatal aneurysm rupture. Treatment of hypertension may reduce the risk of aneurysmal SAH [6].

(3) Alcohol abuse: Excessive alcohol abuse raises the possibility for SAH independent of cigarette smoking, age, and history of hypertension [3].

(4) Genetic risk: The risk of SAH increases seven folds in first-degree relatives of patient; in addition, number of rare inherited conditions (Autosomal dominant polycystic kidney, Ehler-Danlos syndrome) are associated with cerebral aneurysm and SAH [2, 6].

(5) Use of sympathomimetic drugs such as (cocaine) [6].

(6) Female sex: This is believed to be due to estrogen deficiency (estrogen replacement therapy reduces the risk), so it is higher in postmenopausal women than premenopausal ones [3, 6].

(7) Antithrombotic therapy: It increases the severity of the hemorrhage, there are no data to prove whether antithrombotic therapy increases the risk of aneurysmal rupture or not [3, 6].

(8) Inflammation seems to play a vital role in the pathogenesis and growth of intracranial aneurysms. Prominent mediators include the nuclear factor k - light-chain enhancer of activated B cells (NF-κB), tumor necrosis factor, macrophages, and reactive oxygen species. Although there are no controlled studies in humans, 3-hydroxy-3-methylglutaryl coenzyme A reductase inhibitors (statins) and calcium channel blockers could impede aneurysm formation by the inhibition of NF-κB and other pathways [6, 7].

(9) Aneurysm size of 7 mm increases risk of rupture and subsequent SAH [6].

(10) Aneurysm morphology such as bottleneck shape and the ratio of size of aneurysm to parent vessels are associated with rupture of aneurysm [6].

(11) The risk of SAH increases in symptomatic patient with large unruptured cerebral aneurysm especially if it is located either on posterior communicating artery or on the vertebrobasilar system [6].

5. Pathophysiology

Smoking, chronic hypertension, and alcohol abuse lead to weakened arterial tunica media. Chronic exposure to intravascular shear stress leads to pouching of the weakened wall, especially in the vicinity of bifurcations where turbulent flow is prominent.

The aneurysmal rupture is directly proportional to the size of the aneurysm, which is rising from 0.05% in aneurysms less than 10 mm to 6% for those greater than 25 mm.

More than 80% of cerebral aneurysm arises from the anterior carotid circulation (anterior and posterior communicating and middle cerebral arteries), with only 10–20% arising from the posterior vertebrobasilar circulation [1, 2].

Subsequent to aneurysmal rupture, blood spreads quickly within cerebrospinal fluid (CSF), rapidly increasing intracranial pressure (ICP), this sudden increase in the ICP leads to severe headache, cerebral edema, and hydrocephalus. Bleeding usually lasts for a few seconds; however, re-bleeding is common and occurs within the first 24 h. The presence of blood and breakdown products of hemoglobin in the subarachnoid space is responsible for meningeal irritation, meningism, and vasospasm [2].

6. Clinical manifestation

Headache is the hallmark of aSAH in awake patient who describes it "as worst headache in their life," this headache has a sudden onset and immediately reaches maximal intensity (thunderclap headache). Sentinel headache is also reported by 10–43% of patients, which is minor headache, and it is symptoms of minor hemorrhage (sentinel bleed or warning leak). Most of these minor hemorrhages occur within 2–8 weeks before major hemorrhage [6, 8].

The headache may be associated with nausea and/or vomiting, stiff neck, photophobia, brief loss of consciousness, or focal neurological deficits (including cranial nerve palsies).

Seizures occur in about 26% of patients within the first 24 h of SAH, most of the time before medical care is accessed. It is common in presence of intracerebral hemorrhage, in hypertensive patients, and patient with middle cerebral or anterior communicating artery aneurysms [6].

7. Diagnosis

7.1. Non-contrast head CT scan

Non-contrast CT scan is the cornerstone of SAH diagnosis, it confirms the presence of blood clot in subarachnoid space in most of the cases if the scan is performed in the first 24 h, and it may also provide an idea of the cause of the bleeding and site of the aneurysm. In addition to that, it is useful in diagnosis of intraventricular and subdural hematoma [2, 6].

CT scan sensitivity is highest in the first 3 days (close to 100%) and progressively decreases over time to about 58% in the fifth day [6].

7.2. Lumbar puncture

The typical findings are an elevated opening pressure and presence of xanthochromia, which can last for 2 weeks after SAH. Xanthochromia represents hemoglobin degradation products in CSF and indicates that the blood has been in CSF for at least 2 h [6, 9].

7.3. Brain MRI

MRI has advantages over CT brain in detection of subacute subarachnoid hemorrhage (after 4 days), when head CT scan is negative and there is clinical suspicion of SAH, and possibly avoiding the need of lumbar puncture. The most important disadvantages are difficulty in scanning acutely confused ill patient, without sedation for at least 45 minutes, predisposing to motion artifact, and is expensive in comparison with CT [6].

7.4. Digital subtraction angiography (DSA)

Once diagnosis of SAH has been completed, the source of bleeding must be identified with angiographic studies. Digital subtraction angiography (DSA) is the gold standard for the detection of intracranial aneurysm and study of anatomical features of cerebral blood vessels [3, 6].

7.5. CT and MR angiography

Both CT and MR angiography are useful for screening and pre-surgical planning, they can detect aneurysms ≥3 mm with high degree of sensitivity; however, they are less sensitive than conventional angiography. CTA can be achieved immediately after the diagnosis of SAH by CT scan when the patient is still in scanner; CTA is more practical than MRA in acute setting. CTA is used as an alternative to conventional angiography in SAH patients, especially in acute setting and rapidly declining patient who needs emergent craniotomy for hematoma evacuation. CTA can substitute catheter cerebral angiography in older patient with

degenerative vascular disease provided that the quality is excellent and investigation is performed cautiously. Negative CTA should be followed by two- and three-dimensional cerebral angiography in case of diffuse SAH [3, 6]. MRA is rarely indicated in SAH, because of limited routine availability, difficulty in scanning acutely sick patient, who is poorly compliant to commands, which can affect quality of the study, moreover MRA is time consuming and very expensive [6].

8. Grading of SAH

Hard work has been made for the development of scales to clinically grade patients with SAH, to assess the severity of initial injury, to guide treatment decision, to provide prognostic information regarding outcome, and to standardize patient evaluation for scientific study purposes. Since 1933, more than 40 grading systems have been proposed for patients with cerebral aneurysm. Currently, the most commonly used SAH grading scales are the Hunt and Hess scale, Fisher scale, Glasgow Coma Scale (GCS), and the World Federation of Neurological Surgeons (WFNS) scale [10].

8.1. World Federation of Neurosurgeons SAH Scale (WFNS)

In 1998, an expert judgment committee projected the WFNS scale, it was based on GCS and the presence of focal neurological deficit (**Table 2**). Numerous studies found direct association between WFNS grade and outcome [10].

WFNS scale	GCS	Motor deficit, aphasia±hemiparesis or hemiplegia
I	15	Absent
II	14–13	Absent
III	14–13	Present
IV	12–7	Present/absent
V	6–3	Present/absent

Table 2. World Federation of Neurosurgeons SAH scale.

8.2. Prognosis on Admission of Aneurysmal Subarachnoid Hemorrhage (PAASH)

PAASH is solely based on the GCS; it has excellent internal and external validity in regard to clinical outcome. In a study comparing prognostic accuracy of WFNS and PAASH, PAASH had a good prognostic value for patient outcome (**Table 3**) [3].

Scale	Grade	Criteria	Proportion of patient with poor outcome (%)
WFNS	I	GCS 15	14.8
	II	GCS 13–14 no focal deficits	29.4
	III	GCS 13–14 focal deficits	52.6
	IV	GCS 7–12	58.3
	V	GCS 3–6	92.7
PAASH	I	GCS 15	14.8
	II	GCS 11–14	41.3
	III	GCS 8–10	74.4
	IV	GCS 4–7	84.7
	V	GCS 3	93.9

Table 3. Two SAH grading scales with criteria per grade and relation with outcome [3].

8.3. The Hunt and Hess scale

The Hunt and Hess scale was projected in 1968 as an adjustment to an older system initially described by Botterell and colleagues in 1956. The scale was prepared to stratify the surgical risk and to help the surgeon on making appropriate decision in appropriate time. It is well known in the neuroscientific community; however, many of the terms used to define grades, such as drowsy, stupor or deep coma, headache (mild, moderate, severe), nuchal rigidity (slight vs. sever), are subjective and vague which makes this grading system neither reliable nor valid (**Table 4**) [3, 10].

Grade	Clinical description
I	Asymptomatic or minimal headache and slight nuchal rigidity.
II	Moderate to severe headache, nuchal rigidity, no neurological deficit other than cranial nerve palsy.
III	Drowsiness, confusion, or mild focal deficit.
IV	Stupor, moderate to severe hemiparesis, and possibly decerebrate rigidity and vegetative disturbances.
V	Deep coma, decerebrate rigidity, moribund appearance.

Table 4. Hunt and Hess scale.

8.4. Fisher scale

In 1980, the Fisher scale was projected to predict cerebral vasospasm after SAH (**Figure 2**), the scale quantifies the amount of blood seen on CT scan (**Table 5**). It was developed when imaging technology had roughly one-tenth of the resolution currently available. Subarachnoid

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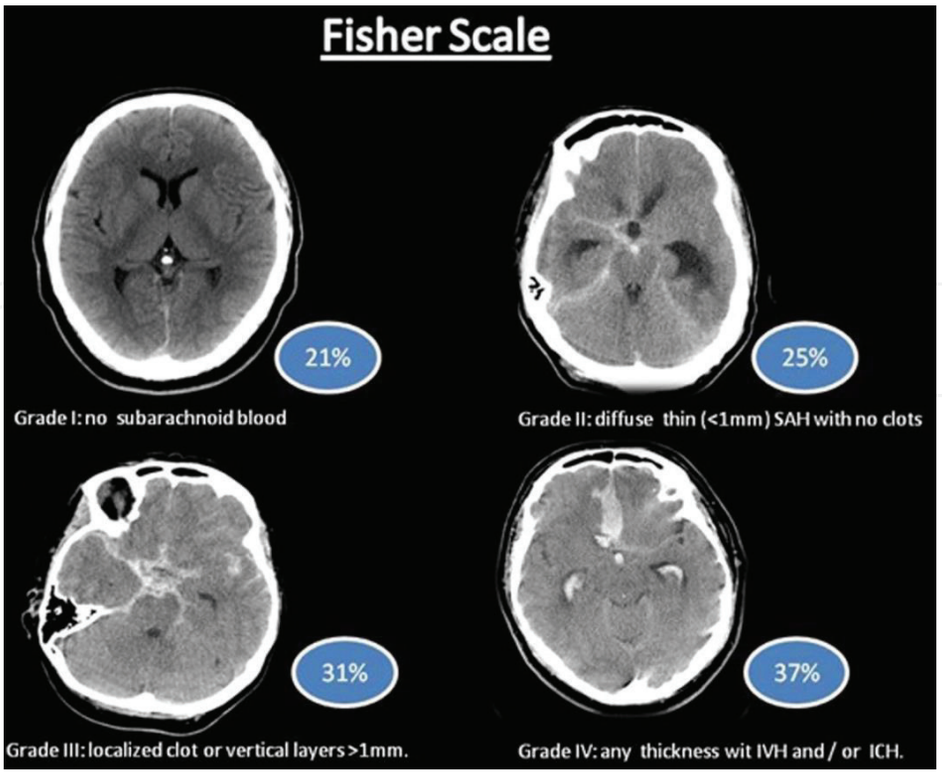

Figure 2. Scale grading system used to quantify the amount of subarachnoid hemorrhage and intraventricular hemorrhage (IVH). The percentages in the circles refer to the risk of vasospasm. Grades III and IV in the scale are the ones with the higher risk to develop "symptomatic vasospasm." Adopted with permission from Ref. [11].

Group	Blood on CT scan
I	No subarachnoid detected.
II	Diffuse or thin vertical layer <1 mm thick.
III	Localized subarachnoid clot and/or vertical layer >1 mm thick.
IV	Intraventricular or intra-parenchymal clot with diffuse or no SAH.

Table 5. Fisher grade scale.

clot less than 1 mm in true thickness is uncommon, as is the finding of no blood on admission CT scan, therefore, grades 1 and 2 were actually be quite uncommon [3, 10].

9. Complications associated with SAH

Complications of subarachnoid hemorrhage can be divided into CNS and systemic compli cations.

9.1. CNS complications

Re-bleeding, vasospasm, hydrocephalus, and seizures are the most important CNS complications of SAH. The high rates of mortality and morbidity after aneurysmal subarachnoid hemorrhage are mainly due to CNS complications.

9.1.1. Re-bleeding

Re-bleeding occurs at a rate of 4–13% in the first 24 h, maximal risk of re-bleeding is in the first 2–12 h, most of re-bleeding (73%) occurs within the first 72 h of initial hemorrhage. Re-bleeding is associated with very high mortality and morbidity, especially if it occurs in the first 12 h after the hemorrhage, the mortality rate reaches to 70% [6, 12].

Many factors are considered as predictor for re-bleeding:

Hunt-Hess grade on admission.

Maximal aneurysmal diameter.

High initial blood pressure.

Sentinel headache preceding SAH.

Longer interval from ictus to admission.

Ventriculostomy before aneurysmal treatment [6, 13].

Re-bleeding diagnosis is based on the deterioration of neurological status and appearance of new hemorrhage in CT scan. Early securing of the aneurysm is the treatment of choice to prevent re-bleeding; however, the optimum time for early intervention is unclear whether intervention within 24 h (ultra-early) is superior to intervention after 3 days [12].

The management of high blood pressure after SAH is still debatable due to the lack of evidence from randomized controlled trial. Data from observational studies propose that aggressive management of blood pressure reduces the risk of re-bleeding, however, at the expense of an increase in secondary ischemia. It looks acceptable but without strong evidence to stop all antihypertensive medications that the patients were taking, and treat hypertension only when it is extremely high. It is very difficult to give limits for extreme blood pressures, because extreme varies between patients and it is affected by many factors such as previous blood pressure, cardiac disease, patient age, and other factors [3].

European stroke organization guidelines for the management of intracranial aneurysm and subarachnoid hemorrhage recommended that the systolic blood pressure should be kept less than 180 mmHg in patients with unsecured aneurysm, till the aneurysm is secured with coiling or clipping. They also recommended keeping mean arterial pressure (MAP) above 90 mmHg when blood pressure is lowered [3].

Nicardipine is short-acting calcium channel blocker, used for smooth control of blood pressure [3, 6].

For patient with an unavoidable delay in obliteration of aneurysm, and great risk of re-bleeding, short-term (72 h) therapy with tranexamic acid or aminocaproic acid is advisable (provided there is no medical contraindication) to decrease the risk of early bleeding. The overall outcome did not noticeably improve in patients treated with tranexamic acid, in spite of a remarkable decrease in re-bleeding [3, 6].

In an uncontrolled study of 18 patients who received an intraoperative dose of Recombinant factor VIIa, no re-bleeding was reported; however, one case had deep venous thrombosis (DVT) and seven had thrombosis in upper extremity in association with peripherally inserted central lines. Currently, there is no evidence to support the use of recombinant factor VIIa [3].

9.1.2. Vasospasm

Vasospasm is luminal narrowing of large cerebral blood arteries after SAH, leading to cerebral ischemia. Vasospasm commonly occurs 3–5 days after initial hemorrhage, with peak vasoconstriction occurring between days 5 and 14; it usually resolves spontaneously after 21 days of SAH. It may manifest in many features such as reduced conscious level, focal neurological deficit, and simply nuchal rigidity; the exclusion of other causes, such as re-bleeding, hydrocephalus, sepsis, and metabolic derangement, is required to confirm the diagnosis [6, 14, 15].

Sometimes there is no correlation between severity of vasospasm and the symptoms of ischemia. There are patients with severe large artery spasm who never become symptomatic and others with quite modest spasm who develop infarction. Possibly various factors play important role in the development of ischemia and infarction, such as distal microcirculatory failure, poor collateral anatomy, and genetic or physiological variations in cellular ischemic tolerance. Vasospasm is confirmed angiographically in 70% of SAH patient , however it manifests as symptomatic spasm in 36% of all patients with SAH [6, 14, 15].

Age more than 80 years, smoking, hypertension, SAH clot volume (a higher Fisher's grade), location of aneurysm (vertebral artery, right sylvian fissure, pericallosal middle cerebral artery [MCA]), left ventricular hypertrophy, and treatment modality are the main risk factors for the development of cerebral vasospasm [15].

Digital subtraction angiography (DSA) is the gold standard diagnostic investigation to diagnose vasospasm (reduced arterial diameter). Computed tomography angiography (CTA) and MRI studies are alternative investigations to DSA [15].

Transcranial Doppler sonography (TCD) can be used at the bedside to aid the diagnosis of vasospasm. The TCD criteria for vasospasm include a mean flow velocity (MFV) greater than 120 cm/s, change in MFV value of more than 50 cm/s over 24 h, and Lindegaard ratio more than 3 (Lindegaard is a ratio derived from concurrent measurements of MFV in MCA and distal ipsilateral extracranial ICA). Diffusion-perfusion mismatch on MRI is an useful investigation for the identification of early stages of vasospasm. Increase in motor-evoked potential threshold more than 50 mA from the baseline value is an accurate indicator of vasospasm.

Inflammatory marker such as C-reactive protein has been investigated for its ability to predict vasospasm. In 93 SAH patients, postoperative and not preoperative C-reactive proteins were associated with vasospasm and poor outcome with a cut-off value of 4 mg/dL [15].

9.1.2.1. Pathophysiology of cerebral vasospasm

It is complicated. Various cascades in affected blood vessels and neurons are in play, they can be grouped into two categories.

9.1.2.1.1. Elevated intracellular calcium

After SAH, calcium influxes into smooth muscle and neuron is rapidly increased through N-methyl-D-aspartate receptor (NMDA) and voltage-gated calcium channels, moreover glutamate is increased and activates NMDA receptors, leading to further calcium influx in smooth muscle, high intracellular calcium concentration enhances binding of calcium to calmodulin. Calmodulin activates myosin light chain kinase (MLCK) to phosphorylate myosin, which induces myosin-actin interaction and smooth muscle contraction and blood vessels constriction [14].

In neuronal cells, increase in intracellular calcium leads to hyperactivation of enzymes, such as protease, endonuclease, phospholipase, which destabilizes cell body and membrane, leading to cellular injury and death [14].

9.1.2.1.2. Vasoactive compound and vessel wall injury

In days 3–5 after SAH, oxy hemoglobin—a red blood cell breakdown product—inhibits nitric oxide (physiologic vasodilator) and stimulates leukocytes to produce endothelin-1 (physiologic vasoconstrictor), resulting in potent vasoconstriction. Furthermore, breakdown of oxyhemoglobin leads to release of reactive oxygen species and iron which leads to oxidative damage to blood vessel walls [14].

In addition, production of vasoactive compounds after SAH, such as serotonin, norepinephrine, and angiotensin II, leads to potent vasoconstriction [14].

9.1.2.2. Treatment of cerebral vasospasm and cerebral ischemia

9.1.2.2.1. Nimodipine

It is L-type calcium channel blocker—it is the only drug that has been approved for SAH in European countries and the USA. It improves long-term neurological outcome if it is started on admission and administered for 21 days. The recommended oral dosage is 60 mg 4 hourly orally (maximum daily dose 360 mg). The role of nimodipine is based on general brain protective mechanism as there is no proof to suggest that it treats angiographically diagnosed vasospasm, and it also increases fibrinolytic activity and inhibits cortical spreading ischemia [2, 6, 12, 15].

Recently, biodegradable silica-based nimodipine implant was effectively used in the management of vasospasm. It is associated with higher nimodipine cerebrospinal fluid (CSF) to plasma ratio than traditional nimodipine [15].

The continuous intravenous infusion of nimodipine is not recommended as it is not superior to oral nimodipine and is associated with high incidence of hypotension especially in hypovolemic patient (an adequate systolic BP of 130–150 mmHg takes priority over nimodipine administration, and it should be stopped if a stable BP can't be maintained).

The recommended dose of Intravenous nimodipine is 1 mg/h in the first 6 h, then increased to 1.5 mg/h in next 6 h, then increased to 2 mg/h (maximum dose) [2, 6, 15].

9.1.2.2.2. Fasudil

It is Rho-kinase inhibitor, it decreases smooth muscle contraction and inhibits TNF-induced IL-6 release from C6 glioma cells, and it causes better angiographic reduction in vasospasm and better neurological outcome than nimodipine. Fasudil is approved for use in Japan and China but not in the USA or Europe [12, 15].

9.1.2.2.3. Triple-H therapy (hemodynamic augmentation therapy)

It is a combination of induced hypertension, hypervolemia, and hemodilution (HHH) to improve blood flow through narrowed cerebral blood vessels due to vasospasm. Triple-H has been for years used as a treatment of choice for the treatment of delayed cerebral ischemia, although the literature supporting its effectiveness and safety is lacking, in fact triple-H therapy is associated with an increase in the risk of systemic complications such as heart failure, pulmonary edema, and infections; therefore, the use of prophylactic triple-H therapy is not recommended [3, 12].

Angiographic vasospasm without a new neurological deficit should not be treated. The development of unexplained new neurological deficit or change in conscious level, immediate aggressive therapy should be started. The first step is a fluid bolus with normal saline to increase cerebral blood flow (CBF) in ischemic area, the goal is to maintain euvolemia. Hypervolemia and hemodilution do not increase cerebral oxygen delivery and might cause adverse events. If patients fail to respond completely to the fluid, management may undergo a trial of hypertension. Blood pressure is increased gradually with the use of a vasopressor. Neurological assessment should be repeated frequently in each blood pressure step (systolic blood pressure 180 mmHg / 190 mmHg / 200 mmHg), and the target should be based on neurological improvement. If the patient did not respond to induced hypertension (systolic blood pressure of 200–220 mmHg), a rescue cerebral angioplasty should be considered [12].

9.1.2.2.4. Balloon angioplasty

Cerebral angioplasty is indicated in symptomatic patient with cerebral vasospasm, who is not responding to hypertensive therapy, Prophylactic angioplasty is not recommended [2, 6, 12].

Cerebral angioplasty may lead to arterial dissection, rupture, thrombosis, infarction, hemorrhage, and reperfusion injury leading to cerebral edema [6, 15].

9.1.2.2.5. Intra-arterial papaverine

Up to 300 mg of papaverine per hemisphere is used for the treatment of distal vasospasm.

The main disadvantages of intra-arterial papaverine may require repeating, relatively short-acting, neurotoxic, seizures, blindness, coma, irreversible brain injury, arrhythmia, and hemodynamic instability refractory to treatment [2].

9.1.2.2.6. Magnesium sulphate

Currently, there is no evidence to support the use of magnesium sulphate ($MgSO_4$) prophylactically or as a treatment modality in delayed cerebral ischemia (DCI). In the Mash 2 Trial, $MgSO_4$ did not improve primary outcome. However, intrathecal and cisternal administration of $MgSO_4$ significantly decreased the severity of vasospasm without any reduction in incidence of DCI or functional outcome [3, 6, 15].

9.1.2.2.7. Statins

Recent meta-analysis reported no role of statin in SAH, and a larger phase 3 trial (Simvastatin in Aneurysmal Subarachnoid Hemorrhage [STASH]) failed to confirm any beneficial effect of statin for long- or short-term outcome and should not be used routinely in acute stage [6, 12, 15].

9.1.2.2.8. Endothelin A-receptor antagonist

Clazosentan (endothelin-1 receptor antagonist) had been presented to be associated with a dose-dependent decrease in the frequency of vasospasm in a phase IIb trial (Clazosentan to Overcome Neurological iSChemia and Infarct OccUrring after Subarachnoid hemorrhage [CONSCIOUS-1]) [6, 15].

Two further trials were carried out:

CONSCIOUS-2: A double blind, placebo-controlled trial, clazosentan was given at a rate of 5 mg/h for 15 days to patients treated with aneurysm clipping. There was statistically insignificant decrease in mortality and vasospasm-related morbidity [15].

CONSCIOUS-3: This study was double blind, placebo- controlled study to assess whether clazosentan reduced vasospasm-related mortality after securing aneurysmal SAH by endovascular coiling. The study was halted prematurely after completion of conscious-2 trial and failed to show any beneficial effect of clazosentan.

It is worth noting that patient who received clazosentan had more pulmonary complications, anemia, and hypotension than the placebo group [6, 15].

9.1.2.3. Other miscellaneous treatments

9.1.2.3.1. Milrinone

In a large case series based on the assessment of all subarachnoid hemorrhage patients diagnosed with delayed ischemic neurological deficit between April 1999 and April 2006, 88

patients were found to have received milrinone infusion for a median of 9.8 days. At 44.6 months, 75% of them had a good functional outcome. Because of obvious limitations in this study, further studies are warranted [15].

9.1.2.3.2. Stellate ganglion block

A small study included 15 patients who had refractory cerebral vasospasm after surgical clipping of aneurysm. Stellate ganglion block was performed using 10 mL of bupivacaine 0.5% on the side with maximum cerebral blood flow velocity. Neurological status, cerebral blood flow velocity, and pulsatility index were assessed before and 10 min, 30 min, 2 h, 6 h, 12 h, and 24 h after stellate ganglion block. The ipsilateral Middle Cerebral Artery (MCA) mean velocity was reduced with reduction in neurological deficit and improvement in GCS; because of obvious limitations in this study, further studies are required [15].

9.1.2.3.3. Albumin

Albumin 25% has been tried to improve outcomes in a pilot study (Albumin in Subarachnoid Hemorrhage trial). The incidence of vasospasm, DCI, and cerebral infarction was significantly reduced with high dose of albumin; however, this is still experimental and further studies are required to support this study [12, 15].

9.1.3. Hydrocephalus

Hydrocephalus is one of the common complications of SAH; it is either acute or chronic.

Acute hydrocephalus occurs in 15–87% of SAH patients as a result of obstruction of CSF flow by blood products or adhesion, some clinician avoid insertion of a ventricular drain in these cases immediately as half of them will recover spontaneously and there is a risk of re-bleeding and infection (meningitis and ventriculitis). Another approach recommended is to start immediate external ventricular drainage (keeping intracranial pressure between 10 and 20 mm Hg), especially when obstructive hydrocephalus is suspected or when the lumbar drainage is contraindicated (sever high intracranial pressure) [3, 6].

It has been recommended to apply lumbar drainage as a consecutive treatment of external ventricular drain (EVD) before shunting in cases with spontaneous intracerebral hemorrhage (ICH) when there is no blood in the third and fourth ventricles (communicating hydrocephalus). This option can be considered as an alternate approach to decrease the occurrence of permanent shunts, improve brain relaxation, and decrease risk of vasospasm; however, this approach may cause downward herniation in some cases such as supratentorial swelling and the development of hygroma. Currently no prospective clinical trial supports lumbar drain insertion either for spontaneous ICH or cases with SAH [3, 6].

Acute hydrocephalus increases risk of cerebral infarction and re-bleeding and eventually may worsen the mortality and morbidity secondary to cerebral infarction and re-bleeding [3, 6].

Chronic shunt-dependent hydrocephalus, which occurs in 8.9–48% of patients with SAH due to a decrease in CSF absorption at the arachnoid granulation, it is usually treated with shunt placement [3, 6].

Many factors are considered as predictor of hydrocephalus:

- Elderly.
- Intraventricular hemorrhage.
- Hypertension.
- Hyponatremia at presentation.
- Low Glasgow Coma Score at presentation.
- Antifibrinolytic agents.

9.1.4. Seizures

More than 26% of patients with SAH experience seizure-like episodes, the majority of such patients report the onset of these seizures occurring before medical care are accessed. There are variable risk factors for the development of early seizures, such as aneurysm in middle cerebral artery, thickness of SAH clot, hypertension, intracerebral hematoma, re-bleeding, cerebral infarction, and poor neurological grade. Routine use of anticonvulsants is associated with worsening of the cognitive function, delayed ischemia, fever, and vasospasm; however, it may be considered in patients with high risk of delayed seizure [3, 6].

9.2. Systemic complications associated with SAH

The high morbidity and mortality associated with SAH is not only due to neurological complications, non-neurological complications also play a major role in increasing mortality and morbidity rates [16].

9.2.1. Cardiac complications

Cardiac complications occur in about 50% of patients with SAH; it ranges from mild elevation in cardiac enzymes and electrocardiogram (ECG) changes to obvious clinical and echocardiographic pathology. Cardiac damage markers are associated with an increased mortality and poor outcome and DCI [16].

9.2.1.1. Pathophysiology

9.2.1.1.1. Mild myocardial injury

This is presented by mild elevation in serum cardiac troponin I (not reaching diagnostic threshold of MI). This elevation occurs in 20–68% of patients with SAH. The degree of neurological injury, as graded by the Hunt-Hess scale, is an independent predictor of myocardial injury in SAH patients. Serum troponin is a powerful predictor for cardiac and pulmonary complications, such as hypotension requiring vasopressor, left ventricular (LV) dysfunction, pulmonary edema, and DCI, especially in patient presenting with a high grade on WFNS.

Serum troponin is a more specific and sensitive indicator of myocardial injury than creatinine kinase-MB; therefore, serum troponin levels and trends must be monitored through serial measurements particularly in SAH patients with past history of cardiovascular disease [16].

9.2.1.1.2. Cardiomyopathy

Neurogenic stunned myocardium (NSM) is the most severe form of myocardial injury in SAH, it occurs in 20–30% of patients with SAH. The elevated level of sympathetic tone leads to calcium overload with reduced sensitization of contractile filaments to this cation, eventually causing myocardial depression. It is characterized by subendocardial contraction band necrosis.

Echocardiography shows abnormal LV contractility and abnormal wall motion, which are reversible but sometimes leads to cardiogenic shock [16].

CK-MB levels, female gender, and poor neurological grade are predictors of LV dysfunction.

Severe LV dysfunction decreases cardiac output (CO) and mean arterial pressure leading to reduction in cerebral blood flow (CBF). Furthermore, LV dysfunction may be associated with cerebral vasospasm and significant decrease in cerebral perfusion pressure therefore, optimization of heart function is critical to prevent progression of neurological dysfunction and to promote recovery in patients with SAH [2, 6, 16–18].

The use of inotropes such as dobutamine or milrinone may be required to optimize cardiac output (CO). In severe LV dysfunction, implementation of intra-aortic balloon pump may be required [2, 6, 16, 18].

9.2.1.1.3. ECG findings

It is common in SAH patients, particularly in the first 3 days of presentation, nearly 50–100% of SAH patients will show different forms of ECG changes such as ST segments changes, T wave changes, QTc prolongation, and Prominent U wave (**Table 6**) [16, 17].

Around 4–8% of SAH patients will have malignant arrhythmias such as ventricular tachycardia (VT), torsade de pointe, and asystole [16, 18].

ECG abnormality	Reported incidence (%)
ST-segment changes	15–51
Inverted or isoelectric T waves	12–92
QTc prolongation	11–66
Prominent U waves	4–47
Sinus bradycardia	16
Sinus tachycardia	8.5

Table 6. ECG changes after subarachnoid hemorrhage [17].

Management of arrhythmias in SAH patients depends upon the type of arrhythmia, clinical significance, and the patient's condition. As a first step, it is vital to assure satisfactory oxygenation and correct electrolyte abnormalities and metabolic disturbance.

The use of beta-blockers to treat cardiac tachyarrhythmia in SAH should be balanced against hypotension and decrease in cerebral blood flow (CBF). A new study concluded that the presence of arrhythmias is associated with poor outcome; in spite of this, no correlation was found between severity of cardiac arrhythmia and the site or the extent of intracranial hemorrhage on CT scan, neurological condition, or the location of ruptured malformation [6, 16, 18].

9.2.2. Electrolyte disturbance

The SAH is associated with different forms of electrolyte disturbances, such as hyponatremia, hypokalemia, hypocalcaemia, and hypomagnesaemia [6].

9.2.2.1. Hyponatremia

Hyponatremia is the most common clinically significant electrolyte derangement associated with SAH. It has an incidence ranging from 35 to 56 %, its diagnostic and therapeutic dilemma needs to be sorted to improve outcome of SAH patient [2, 16, 19].

Syndrome of inappropriate antidiuretic hormone secretion (SIADH) is the most common cause of hyponatremia; other causes are acute cortisol insufficiency, cerebral salt wasting syndrome (CSW), extreme fluid therapy, and/or diuretic therapy.

Kao et al. stated that 34.5% of severe hyponatremia were secondary to SIADH, whereas 23% were considered to be due to CSW. Noteworthy, the patients recruited in this study had more severe SAH than in the comparative studies, and the inclusion criterion was a plasma Na <130 mEq/L [19].

Irrespective of the cause, hyponatremia in SAH patients increases hospital stay, risk of vasospasm, and mortality rate.

The incidence of hyponatremia is associated with the location of aneurysmal rupture. Hyponatremia mostly occurs after rupture of anterior communicating artery (AComA). It was seen in 52.4% of patients with AComA; it may be because the hypothalamus is supplied by branch from AComA [19].

9.2.2.2. Causes of hyponatremia

SIADH is considered the most common cause of severe hyponatremia in SAH; it is secondary to excessive secretion of antidiuretic hormone as a result of stimulation of hypothalamus with traumatic or ischemic factor, causing increased water reabsorption in the distal convoluted tubule of the kidney, resulting in dilutional hyponatremia and fluid retention [19].

In CSW, the increase in urinary sodium excretion and urine output are due to abnormal release of atrial and brain natriuretic hormones, causing reduction in circulating blood volume, as well

as extracellular fluid. Cerebral salt wasting syndrome can be treated with hypertonic saline solution which increases cerebral blood flow, brain tissue oxygen [19].

Clinically, it is very difficult to differentiate between SIADH and CSW syndrome, due to significant overlapping clinical findings between both syndromes: both syndromes are associated with brain lesions; have normal thyroid, adrenal, and kidney functions are hyponatremic, hypouricemic and have concentrated urines, high urinary sodium over 40 mEq/L, and high fractional excretion (FE) of urate. The only clinical difference is the state of their extracellular volume (ECV): being hypervolemic or euvolemic in SIADH and hypovolemic in CSW (**Table 7**) [20].

ECV assessment by usual clinical criteria is very difficult, not accurate to any degree [20].

Determination fractional excretion (FE) of urate is very helpful to differentiate between these syndromes, FEurate, normal 4–11%, has been constantly increased to >11% in both syndromes and has a distinctive relationship to serum sodium in both syndromes. In SIADH, correction of hyponatremia will normalize FEurate to 4–11% but in CSW syndrome FEurate consistently > 11% event after correction of hyponatremia (**Figure 3**).

This algorithm is useful only with normal glomerular filtration rate GFR, because FEurate can exceed normal values in patients with reduced glomerular filtration rate (GFR) [20].

Cortisol deficiency is one of the important causes of hyponatremia, which has not been well investigated in SAH patients because routine examination of adrenocorticotropic hormone (ACTH)/cortisol dynamic is not part of SAH work up [19].

Klose et al. and Parenti et al. investigated pituitary function post-SAH and found that between 7.1 and 12% of patients are cortisol-deficient at the time of presentation with SAH [20].

	SIADH	**CSW**
Plasma volume	↑ or ↔	↓↓
Water balance	↑ or ↔	Negative
Signs and symptoms of dehydration	Absent	Present
Central venous pressure	↑ or ↔	↓↓
Salt balance	Variable	Negative
Hematocrit	↔	↑ or ↔
Serum osmolality	↓↓	↓↓
Urine sodium	↑	↑↑
Urine volume	↓or ↔	↑↑
Plasma BUN/creatinine	↓↓	↑ or ↔
Treatment	Fluid restriction, hypertonic saline, furosemide, demeclocycline	Normal saline, hypertonic saline, fludrocortisone

Table 7. Difference between SIADH and CSW [21].

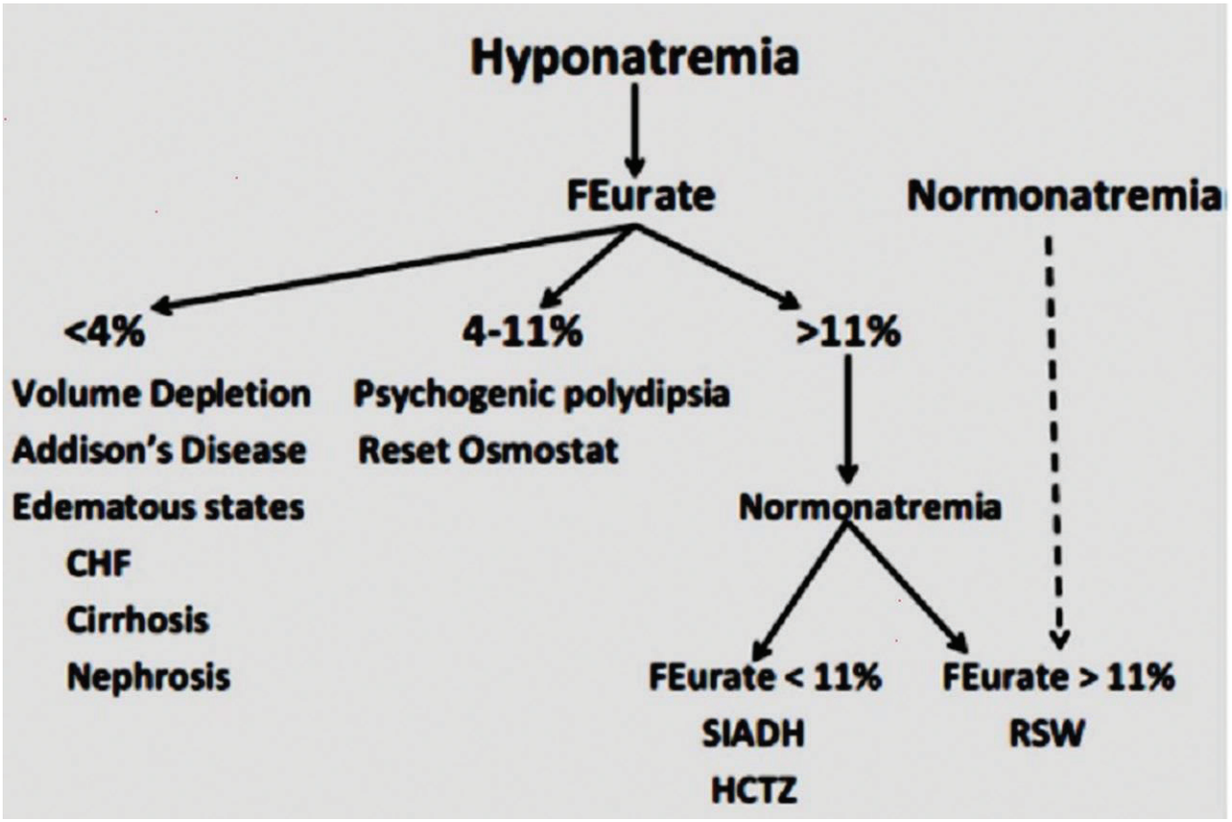

Figure 3. Algorithm for determining the cause of hyponatremia, using FEurate.

9.2.2.3. Treatment of hyponatremia

Patients with SAH should be closely monitored in an intensive care unit, preferably neurointensive care for at least 2–3 weeks post-SAH, to allow for close monitoring of signs and symptoms of delayed cerebral ischemia (DCI), cerebral vasospasm, as well as fluid and electrolyte balance on daily basis, which can help treating doctors in early detection and efficient management of hyponatremia. A daily follow-up of electrolyte is ideal and should be routine. If patients require intravenous hypertonic saline, sodium level should be checked every 4 h.

Urgent investigations of sodium level are mandatory if there are changes in mental status, massive fluctuation of fluid balance, and/or polyuria.

Rapid correction of hyponatremia can cause central myelinolysis and should be avoided, but insufficient correction of hyponatremia can result in brain edema, convulsion, and death [17, 20–22].

Fluid restriction to correct hyponatremia is associated with increased risk of cerebral vasospasm [19, 23].

Audibert et al. looked at the endocrinological response to severe SAH and found alterations in plasma level of numerous hormones such as aldosterone, renin, ADH, angiotensin, ANP, and BNP. However, these changes are noted during the first 12 days post-SAH. It is

not practical to correctly and promptly get hormone levels, because their profile fluctuates frequently.

The expertise recommended that assessing bedside sodium and fluid balance is the best valuable and economical technique for avoiding hyponatremia in patients with SAH [17].

Traditionally, patients with SAH are maintained on sodium chloride-based fluids (i.e., 0.9% saline) for baseline and fluid replacement requirements, to avoid cerebral edema due to fluid shifts across a damaged blood-brain barrier [19].

The recent guidelines of the Neurocritical Care Society for the management of patients with SAH suggested avoiding large amounts of free water intake and fluid restriction to treat hyponatremia [19].

In addition, the guidelines of the American Heart Association recommend that volume contraction be replaced with isotonic fluids (Class IIa, Level B evidence) and that large volumes of hypotonic fluids should be avoided in patients with SAH. The guidelines, however, did not make recommendations on the composition of baseline fluid administration in SAH patients [17].

Recently, Lehmann et al. suggested balanced crystalloids and colloid solutions (those with electrolyte compositions similar to plasma) in SAH patients, which do not cause frequent hyponatremia or hypo-osmolality, also prevent electrolyte imbalance such as hyperchloremia, hyper osmolality, and extreme positive fluid balances associated with saline-based intravenous fluids [19, 24].

Fluid restriction to less than 500 mL/day is the treatment of choice in SIADH, although such approach may not be feasible in SAH, because fluid restriction can cause cerebral vasospasm and subsequently cerebral infarction. What's more, most of these patients are not fully conscious and require enteral feeding which results in a daily fluid intake of 1–2 L [19, 25].

Therapeutic options for water restriction include hypertonic saline solutions and albumin [19]. Hypertonic saline (2–3% solution) not only increases plasma sodium concentration efficiently and rapidly but also increases the risk of pulmonary edema and heart failure and neurological complications secondary to the increase in blood volume [19].

Fludrocortisone causes sodium retention, but it is associated with fluid overload and limited evidence of its effectiveness [19].

Vasopressin receptor antagonists such as conivaptan have been projected and trialed in small studies but have not become routine therapy, because harmful effect secondary to the rapid increase in plasma sodium (4–6 mEq/L) [19, 26].

Acute cortisol deficiency is typically corrected with administration of parenteral hydrocortisone, but the beneficial effect of hydrocortisone is still uncertain and further studies are required, because it is not clear whether corticosteroid therapy is effective in management of acute relative adrenal insufficiency after SAH [19, 27].

Overall, the management of hyponatremia in SAH patients necessitates additional investigation of treatment options that avoid fluid restriction, and further studies will help standardize ideal care.

9.2.3. Fever

Fever is one of the common medical complications of SAH and occurs in 70% of SAH patients. Fever may be due hypothalamic effect of the hemorrhage; it is associated with the severity of the injury, amount of hemorrhage, and development of vasospasm. Effective fever management may improve functional outcome. Paracetamol is the treatment of choice for fever. Active cooling is very effective but adverse effects of shivering may offset its benefit [6, 17].

It is worth noting that the infectious cause such as pneumonia needs to be excluded [17].

9.2.4. Anemia

Anemia is very common and is associated with poor outcome, due to compromising brain oxygen delivery. Correction of anemia and high hemoglobin value improve outcome after SAH. Current guidance recommends to keep hemoglobin concentration between 8 and 10 g/dL [17].

9.2.5. Thrombocytopenia and deep venous thrombosis (DVT)

Heparin-induced thrombocytopenia (HIT) is directly associated with the number of angiographic procedures have been performed. Patients with heparin-induced thrombocytopenia type II seems to be at high risk of thrombotic complications, vasospasm, and poor outcome.

Currently, it is uncertain whether there is practical means of avoiding HIT (as it is essential in angiographic procedures); however, it is vital to know this complication to avoid further heparin exposure and to use non-heparin substitute under the supervision of a hematologist.

DVT is relatively recurrent event after SAH, especially in immobilized patients [3, 6].

Table 8 and **Figure 4** summarize the incidence rate of non-neurological complications.

Complications	Incidence (%)
Fever	54
Anemia	36
Hyperglycemia	30
Hypertension	27
Hypernatremia	22
Pneumonia	20
Hypotension	18
Pulmonary edema	14
Hyponatremia	14
Life-threatening arrhythmia	8
Myocardial ischemia	6

Table 8. Non-neurological complications of subarachnoid hemorrhage [17].

http://dx.doi.org/10.5772/intechopen.68630

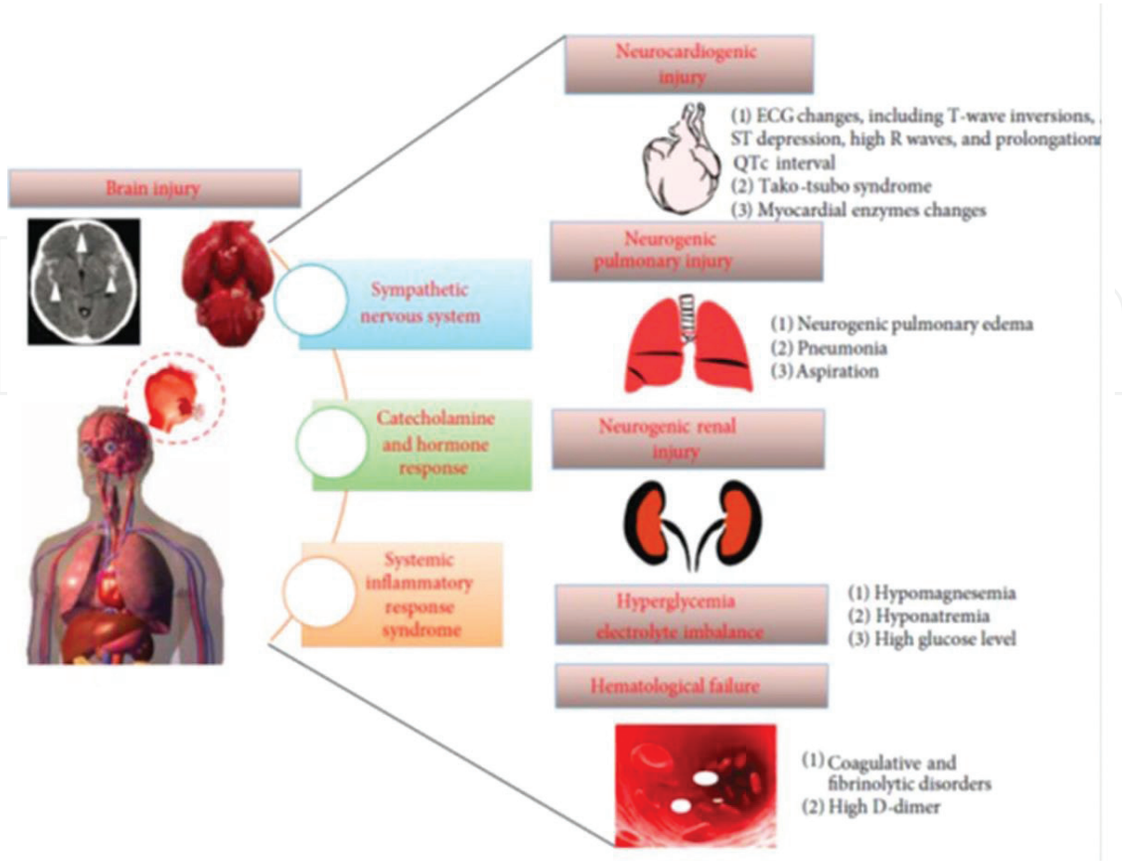

Figure 4. Harmful effects of SAH on extracerebral organs [28].

10. Surgical and endovascular methods for treatment of ruptured cerebral aneurysms

Ruptured aneurysms can be cured by microsurgical clipping or endovascular coiling.

Microsurgical clipping requires craniotomy to prevent re-bleeding of the aneurysm via insertion of a clip through its neck, thus isolating the aneurysm from circulation. This technique conveys a 98% certainty of elimination of the risk of rupture [29].

Endovascular coiling is the blocking of an aneurysm by an endovascular approach with electrically detachable platinum coils device which induces secondary thrombosis of the aneurysm [6]. The first published prospective randomized outcome study of surgical versus endovascular coiling, concluded that endovascular treatment results in clinical outcomes equal to that of surgical clipping.

Koivisto and co-worker (2000) published first prospective randomized outcome study of surgical versus endovascular coiling, they concluded that endovascular treatment results in clinical outcomes equal to that of surgical clipping [30].

The International Subarachnoid Aneurysm Trial (ISAT) is the first multicenter prospective randomized trial comparing the two options; the included 2143 patients with ruptured intracranial aneurysms were randomly assigned to clipping (1070) or coiling (1073). Primary outcomes included death or dependent living, and secondary outcomes included risk of seizures

and risk of re-bleeding. Initially, 1-year outcomes concluded a fall in death and disability from 31% in the clipping arm to 24% in the endovascular arm, this difference was mainly driven by a reduction in the rate of disability among survivors (16% in the endovascular arm and 22% in the clipping arm) [6, 29, 30].

The risk of epilepsy and significant cognitive decline was also reduced in the endovascular group, but the occurrence of late re-bleeding was increased in endovascular group (2.9% after endovascular repair vs. 0.9% after open surgery) and only 58% of coiled aneurysms were completely obliterated compared with 81% of clipped aneurysms [6].

Although these results have affected the approach to patients with intracranial aneurysm in neurosurgical centers across the world, the study has been criticized due to the lack of generalizability, for example, posterior circulation aneurysms, which account for 8% of patients admitted with subarachnoid hemorrhage and up to 48% of ruptured aneurysms managed by endovascular coiling at some centers, made up only 2.7% of the ISAT study population [30].

Tahir et al. [29] concluded no significant difference in the clinical outcome of coiling and clipping of ruptured intracranial aneurysms; however, clipping is more cost effective than coiling.

Clipping is recommended for middle cerebral artery aneurysms (difficult to treat with endovascular technique) and patients presenting with an intraparenchymal hematoma >50 mL (high occurrence of critical outcome). Endovascular coiling is the preferred technique for patients presenting with vasospasm, elderly, poor clinical grade, and posterior cerebral aneurysms [6].

11. Time of surgical intervention

The most important strategy to reduce the risk of aneurysm rupture is early aneurysm repair, although evidence for best time of intervention is limited, it is uncertain whether ultra- early treatment (before 24 h) is better than aneurysm repair within 72 h (early). Recently published data analysis suggested that the surgical intervention can be done safely within 72 h after SAH. The American Heart Association/American Stroke Association recommend that "surgical clipping or endovascular coiling of the ruptured aneurysm should be performed as early as feasible in the majority of patients to reduce the rate of re-bleeding after SAH" (Class 1B). This recommendation is supported by the European Stroke Organization Guidelines for the Management of Intracranial Aneurysms and Subarachnoid Haemorrhage, which indicated that "aneurysm should be treated as early as logistically and technically possible to reduce the risk of re-bleeding; if possible it should be aimed to intervene at least within 72 hours after onset of first symptoms." There is ongoing study that only recruiting SAH with poor grade may help answer the question of whether intervention within 72 h (early intervention) is associated with better outcome compared with intervention within 4–7 days [12].

12. Prognosis and outcome

In spite of improvement in interventional and medical treatment of SAH, rupture of an aneurysm is still associated with significant high mortality rates (about 33%) and sever disability

(17%). In last decades, mortality rates decreased by 17%, and the chance to recover to independent state has increased by 1.5% per year. Severity of initial bleeding plays a vital role in the determination of mortality rate and functional outcome [3].

Age is another important factor: mortality rate increased three times if the patient was older than 80 years. Aneurysm size, site, history of hypertension, high systolic pressure, history of alcohol consumption, cigarette smoking are all important factors associated with poor outcome regardless the severity of SAH [3].

Complications such as re-bleeding, DCI, hydrocephalus, hyperglycemia, metabolic disturbances, cardiopulmonary complications, prolonged bed rest are associated with increased probability of poor outcome.

Small studies suggest that increased catecholamine levels in cerebrospinal fluid (CSF) are associated with early mortality or disability. Serum S100 is another marker of poor outcome after SAH [3].

13. Conclusion

Aneurysmal SAH is a devastating neurovascular disease associated with very high mortality and morbidity despite improvement in interventional and medical treatment due to multiple neurological and systemic complications, especially re-bleeding and DCI secondary to vasospasm. Age, smoking, alcohol consumption, hypertension, site and size of aneurysm are important factors associated with poor outcome. SAH needs multidisciplinary specialized care, best provided in high-volume centers to improve outcome.

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