Subarachnoid haemorrhage disease and the anaesthetist

Introduction

Aneurysmal subarachnoid haemorrhage (SAH) accounts for approximately 85% of all episodes of non-traumatic subarachnoid haemorrhage. Bleeds from arteriovenous malformations in the brain and the spine account for a further 5%. The remainder are due mainly to intracerebral haemorrhages.1 Acute SAH is associated with a high mortality. Even for those who survive the acute event, the associated morbidity is significant. Involvement in the management of a patient who has suffered an aneurysmal SAH will depend on each anaesthesiologist’s individual practice profile. For many anaesthesiologists, this may be restricted to the immediate pre-operative, intra-operative and postoperative care of the patient. For anaesthesiologists involved in critical care medicine, the care period may extend right from the initial resuscitation and investigation on admission to the management of vasospasm postoperatively. Regardless of the degree of involvement, a clear understanding of the underlying pathophysiology of the disease process is essential in order to manage SAH patients appropriately and effectively. This review will be restricted to the discussion of aneurysmal SAH.

Epidemiology

The estimated incidence of intracranial aneurysm (ICA) in North America is 2 000 per 100 000, or 1 in 50 of the population.2 The annual incidence of rupture of ICA leading to SAH is, however, only 10.5 to 12 per 100 000.4,5 This translates to an overall estimate of 30 000 Americans being affected by SAH disease each year.4 Figures from the UK are marginally lower at 8 - 10 per 100 000. The mean age of patients suffering an acute SAH is 55 years, with most patients presenting in the fifth and sixth decades.5 Other sources quote 61 years as the mean age for SAH.1 A female preponderance of between 1.6:1 to 2:1 exists.1,5 Twice as many black people develop SAH as white people.3

Pathophysiology

The aetiology of intracranial aneurysms is multifactorial. Genetic factors are implicated in intracranial aneurysms, with a seven-fold increase in risk noted in first degree relatives of patients.3 Smoking is associated with a staggering eleven-fold increased risk, while

Anatomy of the circle of Willis

The diagram depicts a standardised circle of Willis, but considerable anatomic variation exists. In a study of over 1 400 brains, the classic anatomy of the circle was only seen in 34.5% of the sample. The internal carotid arteries arise from the common carotid arteries, with the posterior communicating artery given as a branch of the internal carotid artery just before it divides into its terminal branches: the anterior and middle cerebral arteries. The anterior cerebral artery forms the anterolateral portion of the circle of Willis, while the middle cerebral artery does not contribute to the circle.

The posterior cerebral arteries arise from the basilar artery, which is formed from the left and right vertebral arteries. The anterior communicating artery connects the two anterior cerebral arteries, and could be said to arise from either the left or right.

Illustration from Grey’s Anatomy out of copyright
hypertension only carries a three-fold increased risk. Along with alcohol abuse, all of these factors contribute to weakened arterial tunica media. Chronic subjection to intravascular shear stress results in pouching of the weakened wall, particularly in the vicinity of bifurcations where turbulent flow is prominent. La Place’s law applies to aneurysmal wall tension and predisposes to continued growth in size of the aneurysm. The annual risk of rupture increases with the size of the aneurysm, rising from 0.05% in aneurysms less than 10 mm, to 6% for those greater than 25 mm.

The majority of cases arise from the anterior carotid circulation (anterior and posterior communicating and middle cerebral arteries), with only 10 - 20% arising from the posterior vertebrobasilar circulation.

Following rupture of the aneurysm wall, blood continues to be pumped into the subarachnoid space until the pressure gradient has equalised, with pressure within the subarachnoid space now equalising systemic arterial pressure. This phase is short-lived, lasting several minutes only. The sudden rise in pressure accounts for the excruciating headache that accompanies SAH. Other important sequelae include cerebral oedema and hydrocephalus, the latter resulting from decreased absorption of cerebrospinal fluid (CSF) due to blood clots on the subarachnoid granulations, and/or blood clot obstruction to CSF drainage from the ventricles. The presence of blood in the subarachnoid space is associated with meningeal irritation and meningism. The blood and breakdown products of haemoglobin in the subarachnoid space are thought to provide the stimulus for vasospasm. The degree of vasospasm accompanies SAH. Other important sequelae include cerebral oedema and hydrocephalus, the latter resulting from decreased absorption of cerebrospinal fluid (CSF) due to blood clots on the subarachnoid granulations, and/or blood clot obstruction to CSF drainage from the ventricles. The presence of blood in the subarachnoid space is associated with meningeal irritation and meningism. The blood and breakdown products of haemoglobin in the subarachnoid space are thought to provide the stimulus for vasospasm. The degree of vasospasm appears linked to the volume and site of blood within the subarachnoid space. In a third of SAH patients, the development of intracerebral granulations, and/or blood clot obstruction to CSF drainage from the ventricles. The presence of blood in the subarachnoid space is associated with meningeal irritation and meningism. The blood and breakdown products of haemoglobin in the subarachnoid space are thought to provide the stimulus for vasospasm. The degree of vasospasm appears linked to the volume and site of blood within the subarachnoid space. In a third of SAH patients, the development of intracerebral and intraventricular haematomas contribute to a further increase in intracranial pressure (ICP).

Diagnosis

There are a number of special investigations that will confirm the diagnosis and determine the site of the aneurysmal rupture. The pattern of blood in the basal cisterns demonstrated by computerised tomography (CT) may provide a suggestion of the source of the bleed. In CT negative cases, the presence of xanthrochromia in the CSF sample obtained from a lumber puncture 6-12 hours after the onset of headache will confirm SAH. Cerebral angiography, however, remains the gold standard for the imaging of intracranial aneurysms. It is invasive and is associated with risks of serious complications including rerupture of the aneurysm. CT and magnetic resonance imaging (MRI) angiography are minimally invasive, but have a lower sensitivity and specificity when compared to cerebral angiography.

Prognosis

Overall, SAH does not have a good prognosis. Aneurysmal SAH carries a 30 day mortality of 45%. Almost all deaths occurring within the first three weeks are due to a rebleed or to vasospasm. Of those patients surviving this initial period, one third will have moderate to severe disability, and at least half will have significant long-term cognitive dysfunction.

An editorial that appeared in Stroke provides a more positive perspective. In the Cognitive Function After Aneurysm Surgery Trial (CFAAST), the investigators determined that neurocognitive improvement continued well beyond three months, with a plateau being reached between nine and fifteen months after the initial bleed. CFAAST was a longitudinal study designed to provide long-term follow-up for patients enrolled in the original Intraoperative Hypothermia for Aneurysm Surgery Trial (IHAST) that will be referred to later. Based on these findings, one should perhaps not be in too great a hurry to prognosticate on such cases within the immediate postoperative period.

The three main predictors of mortality and dependence after SAH are:

1. An impaired level of consciousness on admission (see Table I and II);
2. Advanced age;
3. A large volume of blood on the initial cranial CT scan (see Table III).

Table I: Hunt and Hess grading scale for subarachnoid haemorrhage

<table>
<thead>
<tr>
<th>Grade</th>
<th>Clinical description</th>
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<tbody>
<tr>
<td>L</td>
<td>Asymptomatic or minimal headache and slight nuchal rigidity</td>
</tr>
<tr>
<td>LI</td>
<td>Moderate to severe headache, nuchal rigidity, no neurological deficit other than cranial nerve palsy</td>
</tr>
<tr>
<td>LII</td>
<td>Drowsiness, confusion, or mild focal deficit</td>
</tr>
<tr>
<td>IV</td>
<td>Stupor, moderate to severe hemiparesis, and possibly early decerebrate rigidity and vegetative disturbances</td>
</tr>
<tr>
<td>V</td>
<td>Deep coma, decerebrate rigidity, and moribund appearance</td>
</tr>
</tbody>
</table>

Table II: World Federation of Neurological Surgeons (WFNS) grading scale for aneurysmal subarachnoid haemorrhage

<table>
<thead>
<tr>
<th>Grade</th>
<th>Glasgow Coma Scale score</th>
<th>Motor deficit*</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>15</td>
<td>Absent</td>
</tr>
<tr>
<td>LI</td>
<td>13 or 14</td>
<td>Absent</td>
</tr>
<tr>
<td>LII</td>
<td>13 or 14</td>
<td>Present</td>
</tr>
<tr>
<td>IV</td>
<td>7 – 12</td>
<td>Present or absent</td>
</tr>
<tr>
<td>V</td>
<td>3 – 6</td>
<td>Present or absent</td>
</tr>
</tbody>
</table>

*Excludes cranial neuropathies, but includes dysphasia

Table III: Fisher Grading Scale of Cranial Computerised Tomography

<table>
<thead>
<tr>
<th>Grade</th>
<th>Findings on Cranial computerised tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No subarachnoid blood detected</td>
</tr>
<tr>
<td>2</td>
<td>Diffuse or vertical layers &lt; 1 mm</td>
</tr>
<tr>
<td>3</td>
<td>Localized clot and/or vertical layer &gt; 1 mm</td>
</tr>
<tr>
<td>4</td>
<td>Intracerebral or intraventricular clot with diffuse or no SAH</td>
</tr>
</tbody>
</table>
Grading scales such as these above are utilised to standardise clinical assessment and estimate prognosis. The higher clinical scales are associated with a higher incidence of complications, such as cerebral vasospasm, elevated ICP, impaired cerebral autoregulation, impaired vascular CO₂ reactivity, cardiac arrhythmias and dysfunction, hypovolaemia, and hyponatraemia.1

Medical complications of subarachnoid haemorrhage

The complications of subarachnoid haemorrhage are not confined to the central nervous system (CNS). Medical complications other than those of the CNS contribute significantly to morbidity and overall mortality. In a large multicentre study involving 41 neurological centres in the United States and Canada, with a total of 457 patients with SAH enrolled, major non-neurological medical complications accounted for 23% of deaths.12 Compare this to 19% attributed to the direct effects of the initial hemorrhage, 22% due to rebleeding and 23% due to vasospasm. 40% of patients were found to have experienced at least one life-threatening medical complication. Major cardiovascular complications accounted for most of the medical complications, with a 23% incidence of pulmonary oedema (PE). Interestingly, the association of PE was significant in relation to the timing of the surgery (p < 0.05), but not the use of triple-H therapy (p = 0.1).12

In addition to PE, the other common cardiovascular complications associated with SAH were marked systemic and pulmonary hypertension and myocardial dysfunction, including cardiac arrhythmias and myocardial damage. ECG abnormalities have been reported at anywhere between 25 - 100% of SAH patients. Elevation of cardiac enzymes was not uncommon, with 17 - 28% demonstrating elevated cardiac troponin and 37% showing elevation in creatine kinase MB isoenzyme.5 The syndrome of neurogenic stunned myocardium is the most severe form of cardiac injury associated with SAH, and is characterised by reversible left ventricular systolic dysfunction, cardiogenic shock and PE.5

The underlying mechanism for the apparent myocardial dysfunction is thought to be a massive myocardial release of catecholamines from sympathetic nerve terminals, causing calcium overload and myocyte necrosis. SAH is associated with elevated sympathetic tone and increased plasma concentrations of catecholamines. Interestingly, the degree of myocardial dysfunction correlates more with the neurological deficit than the severity of ECG abnormalities.5

This association between neurological deficit and myocardial dysfunction is demonstrated in Table IV. The data is derived from a study investigating ECG and echocardiographic changes in patients with intracranial aneurysms.2

The dilemma for the anaesthetist or intensivist is how to interpret these signs of myocardial injury associated with SAH and how to manage them, as they do not necessarily correlate with similar findings in a primary myocardial injury unassociated with SAH. It would, however, seem prudent in the presence of signs of cardiac dysfunction or myocardial injury to very carefully consider the possible risks before embarking on triple-H therapy, bearing in mind the therapeutic goals of increased blood pressure and cardiac filling.6

Cerebral vasospasm

In 60 – 70% of patients, SAH is complicated by cerebral vasospasm. Although the cause of this phenomenon is still unknown, a longstanding theory holds that the balance between endothelin and nitric oxide is disturbed by free oxyhaemoglobin in the CSF, leading to prolonged vasoconstriction.3 Vasospasm is a major contributor to morbidity and mortality in SAH. The effects of the resultant cerebral ischaemia may vary from subtle neurological signs to frank cerebral infarction and, in up to one third of patients, death. It usually develops within the first week, with peak incidence at 7 - 10 days post-SAH. Resolution occurs within three weeks.

Noninvasive sequential transcranial Doppler detection of blood velocity changes is used to detect vasospasm in asymptomatic patients. Normal cerebral blood flow velocity is 80 – 100 cm/s, and any measurement that is greater than 50 cm/s above baseline is predictive of vasospasm.1 However a high level of sensitivity and specificity for the detection of vasospasm can only be achieved in experienced hands, and then only of the middle cerebral artery. It is significantly less successful for detecting vasospasm in the anterior cerebral artery and posterior circulation.2 Although cerebral angiography for vasospasm will be positive in up to 70% of cases, only 20 - 30% of these will be symptomatic.5

Table IV: Number of SAH patients without heart disease with abnormalities of the ECG and echocardiogram (ECHO)5

<table>
<thead>
<tr>
<th>Neurological grade</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECG normal ECHO normal</td>
<td>7</td>
<td>13</td>
<td>3</td>
<td></td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>ECG acute change ECHO normal</td>
<td>1</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>ECG acute change ECHO motion abnormality</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>21</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>41</td>
</tr>
</tbody>
</table>

Treatment modalities for cerebral vasospasm

Nimodipine

Therapy with nimodipine has been shown to improve the outcome of SAH if it is initiated on admission and continues for 21 days.13 Although nimodipine can be administered both orally or intravenously, the preferred route of administration is per os or nasogastric tube. The recommended oral/nasogastric dosage is 60 mg every 4 hours, with a maximum daily dose of 360 mg. Nimodipine should be administered for the full 21 days.

The intravenous administration of nimodipine as a continuous infusion is associated with a high incidence of hypotension, and is no more effective than when given orally. The recommended intravenous dose is 1 mg per hour during the first 6 hours. In the
absence of hypotension, the dosage may be gradually increased as follows:

- Increased to 1,5 mg per hour for the next 6 hours;
- Increased to the maximum dose of 2 mg per hour thereafter.

The following additional recommendations apply to intravenous infusion of nimodipine:

- Nimodipine should be administered via a central line to avoid thrombophlebitis.
- The administration system must be protected from light.
- An adequate systolic blood pressure of 130 – 150 mm Hg takes priority over nimodipine administration, and it should be discontinued if a stable blood pressure cannot be maintained.

This hypotensive effect is more pronounced in the presence of hypovolaemia and with the induction of anaesthesia. The beneficial effects of nimodipine may be based more on a general brain protective mechanism, as there is no evidence to suggest that it relieves angiographically documented vasospasm.5

**Triple-H therapy**

Triple-H therapy is a combination of induced hypertension, hypervolaemia, and haemodilution. The indications for initiating triple-H therapy in SAH patients include a noted increase in transcranial Doppler velocities and/or the development of new neurological deficits. Increases in transcranial Doppler velocities are seen as an indication of cerebral vasospasm. The underlying theory is that, during vasospasm, cerebrovascular resistance is determined by blood vessels that lack effective autoregulation. Hence cerebral blood flow (CBF) now becomes pressure-dependent. The aim of therapy is therefore to reverse cerebral ischaemia by increasing perfusion pressure, while at the same time decreasing the blood viscosity. Thereby, CBF is effectively increased to the affected areas.

Blood pressure elevation is achieved via fluid administration and cardiocirculatory drugs. Commonly used drugs include dopamine, noradrenaline and metaraminol.5,14 In a study utilising xenon-enhanced CT to measure CBF before and after dopamine administration, improved CBF flow to ischaemic areas and reduced flow to hyperaemic areas in response to dopamine administration was demonstrated.15 Generally, aggressive fluid loading with hetastarch solutions or albumin should precede the administration of dopamine or norepinephrine.

The targets for triple-H therapy are as follows:5

- Systolic blood pressure elevation to approximately 120 – 150 mm Hg in unclipped, and 160 – 200 mm Hg in clipped, aneurysms.
- Central venous pressure of 8 – 12 mm Hg, or pulmonary artery wedge pressure of 15 – 18 mm Hg.
- Haematocrit of 30 – 35%.

Before proceeding to triple-H therapy, we need to be aware of its probable limitations and associated risks. To start with, most neurosurgeons do not recommend triple-H therapy in unclipped aneurysms. Furthermore, although it will reverse neurological symptoms in up to 70% of patients with vasospasm, triple-H therapy has not proved effective in reducing the incidence of delayed ischaemic neurological deficits or death after SAH, and it may actually increase patient mortality.5 The serious complications that are associated with this form of therapy include PE, myocardial ischaemia, respiratory failure and electrolyte disturbances such as hyponatraemia. The latter may develop in SAH in the absence of triple-H therapy, and is likely to be the result of cerebral salt-wasting syndrome (CSWS) or the syndrome of inappropriate secretion of anti-diuretic hormone (SIADH). Triple-H therapy in the presence of cardiac dysfunction is not advised. Nevertheless, should the decision be made to undertake triple-H therapy in this setting, consideration should only be given after confirming the transcranial Doppler-detected vasospasm with catheter angiography. Full invasive haemodynamic monitoring, including pulmonary artery catheterisation or transoesophageal echocardiography or both, is considered mandatory under these circumstances.

**Balloon angioplasty**

A more recent development in the management of vasospasm is the use of balloon angioplasty, often combined with the intra-arterial administration of papaverine. Before embarking on balloon angioplasty in patients with persistent new neurological deficits that are unresponsive to medical therapy, the following investigations must be performed:

- Urgent catheter angiography to confirm segmental stenosis which reflects vasospasm of the distal carotid artery, the proximal M1 and A1 segments, or the vertebral and basilar artery;
- Cranial CT must be performed to rule out infarction in the area supplied by the spastic vessels.

Transluminal balloon angioplasty of the vasoconstricted vessels may then be performed, with or without the concomitant intra-arterial administration of papaverine.5

**Intra-arterial papaverine**

Intra-arterial papaverine, up to 300 mg per hemisphere, has been utilised for more distal segment vasospasm.16 However, when balloon angioplasty is feasible, it is considered the more effective treatment option. Papaverine is neurotoxic and may result in blindness, seizures, coma and irreversible brain damage.17

**Hydrocephalus**

Hydrocephalus should be excluded by CT scan, in the presence of deteriorating neurological signs, before a diagnosis of vasospasm is made. Both communicating hydrocephalus, the result of reduced CSF absorption, and non-communicating hydrocephalus, the result of CSF drainage obstruction, are encountered in SAH (see Pathophysiology
above), and may require external ventricular drainage. Continuous ICP monitoring should be considered in poor grade patients with hydrocephalus.

Hypertension

The dangers of causing possible cerebral ischaemia need to be carefully considered when treating hypertension in SAH. Systolic pressures in excess of 180 mm Hg despite nimodipine therapy may, however, be considered suitable for antihypertensive treatment with labetalol or ACE inhibitors.

Seizures

These may occur at the time of rupture, as a result of hypoxia. SAH patients will remain seizure-prone for 18 months thereafter.

Electrolyte disturbances

Hyponatraemia, hypokalaemia, hypocalcaemia and hypomagnesaemia are common in SAH, and should be monitored and treated appropriately.

The differentiation between the two most common causes of hyponatraemia in this setting can be made on fluid balance:

- Cerebral salt wasting syndrome, due to the secretion of brain and atrial natriuretic hormone, is accompanied by a negative sodium balance and an intravascular volume depletion;
- SIADH is accompanied by the accumulation of an excess of free water with a high central venous pressure (CVP).

Timing of surgery

There are advantages and disadvantages to early and late surgery. Early surgery reduces the risk of a further bleed, but has the disadvantage of being associated with poor operating conditions. Late surgery has the advantage of providing excellent operating conditions but, as was shown in the co-operative study on the timing of aneurysm surgery, 30% of the patients randomised to undergo late surgery did not survive until the planned surgical intervention. The period from 7 to 10 days post SAH, which represents the peak period for vasospasm, has been associated with the poorest outcome for surgery.

Anaesthesia for the clipping of intracranial aneurysms

Aims of anaesthesia

There are certain broad principles or goals that apply to the anaesthetic management of intracranial aneurysm surgery. The actual techniques employed are of lesser importance.

The primary goals should be:

- The control of the transmural pressure gradient (TMPG) across the aneurysm wall, as this is paramount to the prevention of inadvertent aneurysm rupture;
- The optimisation of cerebral oxygenation and perfusion;
- The optimisation of ICP, and the avoidance of large and sudden fluctuations in ICP;
- The provision of cerebral protection during ischaemic periods;
- The provision of optimal operating conditions, and surgical exposure with the least brain retraction.

Other issues that need to be taken into consideration, and that may contribute to the achievement or form part of the above, include:

- The optimisation of ventilation to achieve:
  - Low mean airway pressure, to avoid increasing ICP;
  - Normocapnia, at around 4.5kPa:
    - The avoidance of hypocapnia to prevent cerebral vasoconstriction and resultant ischaemia;
    - The avoidance of hypercapnia to prevent cerebral vasodilatation and resultant increased ICP.
- The prevention or treatment of cerebral oedema, This can be achieved with careful fluid administration, including the avoidance of excessive crystalloid infusion.
- Adequate preparation to manage potential intra-operative problems, such as aneurysm rupture.
- Provision of adequate analgesia to obtund painful stimuli, such as intubation of the trachea and head pin placement.
- Provision for rapid emergence, to facilitate early postoperative neurological assessment.

Preoperative assessment

These patients will require a very thorough preoperative assessment. In addition to the standard considerations, careful attention must be paid to the cardiovascular status of the patient, as this is most likely to be affected. (see Pathophysiology above.)

Fluid Management

Careful consideration of the patient’s hydration status is essential. The vomiting associated with SAH, reduced fluid intake and the diuretic effect of contrast injections, coupled with the vasodilatory effects of nimodipine, can produce significant relative hypovolaemia. In poor grade patients, CVP monitoring of fluid status is essential. In addition to fluid volume derangements, electrolyte disturbances (see above) are common and need to be monitored and corrected preoperatively.

Premedication

Poor grade patients should not receive any premedication. Good grade patients, in addition to reassurance, may require mild benzodiazepine premedication. Sedation is not encouraged, as it may mask underlying neurological deterioration preoperatively.
**Induction of anaesthesia**

The main aim of the induction is to provide a very smooth transition from the awake state to the anaesthetised state, without incurring significant haemodynamic changes. No specific technique has been shown to have an outright advantage. Popular combinations are thiopentone/propofol with fentanyl/alfentanil, or propofol with remifentanil. The latter combination is preferred as part of a total intravenous anaesthesia (TIVA) technique.

**Monitoring**

In addition to the standard monitoring (including ECG, pulse oxymetry, NIBP and capnography), the placement of an intra-arterial line pre-induction is recommended. The main reason for placing the line awake is to be able to rapidly address any haemodynamic changes during induction.

The need for CVP monitoring will be very much dependant on the patient’s general status. Although CVP, and even pulmonary artery monitoring, was considered essential in SAH, this practice has largely been discontinued as the added risk of placing a central line probably outweighs any benefit for the majority of patients. However, in poor grade patients or patients with significant cardiovascular dysfunction, CVP monitoring is considered essential.

Bispectral index (BIS) monitoring will be required if brain protection with doses of thiopentone or propofol, sufficient to produce significant burst suppression, are being considered.

Neuromuscular relaxation should be monitored continuously to avoid the disaster of a patient moving or coughing during the procedure. This can have catastrophic results in terms of a rupture of the aneurysm, or a sudden increase in ICP.

**Choice of technique for the maintenance of anaesthesia**

There is currently no evidence to suggest that a propofol TIVA-based anaesthetic has any advantage over an isoflurane/sevoflurane inhalational-based anaesthetic, in terms of patient outcome. Nitrous oxide was used as part of maintenance of anaesthesia for intracranial aneurysm surgery in the IHAST study, and is used in centres such as Helsinki University Central Hospital.

An inhalational technique is usually supplemented with fentanyl or remifentanil. My personal opiate of choice is sufentanil. Although this has been associated with increased CBF when compared to fentanyl, this only applies when dosages much higher than those normally required in intracranial neurosurgery have been administered. In a study looking at continuously measured middle cerebral blood flow, there was no difference between recorded blood flows when comparing fentanyl 25 µg/kg with sufentanil 3 µg/kg. Increased flow was only demonstrated in the group receiving sufentanil 6 µg/kg.

If higher doses of fentanyl or sufentanil are to be avoided, it becomes essential to supplement painful events, such as the head pin placement, with 1 mg of alfentanil. In patients receiving remifentanil, a small bolus of the drug can be given immediately before the pins are placed. In my experience, other techniques, such as local infiltration or deepening the level of anaesthesia, are not adequate to blunt the hypertensive response that accompanies head pin placement.

More importantly, the goals of maintenance of a compliant brain and maintenance of cerebral perfusion Pressure (CPP) will dictate the technique.

**Cerebral protection**

The use of mild hypothermia for cerebral protection was, until recently, a very popular technique in intracranial aneurysm surgery. That was until the IHAST study, conducted in 30 centres and 1 001 patients, demonstrated that neurocognitive improvement was not effected by the use of intra-operative hypothermia in good grade patients with SAH.

Despite the lack of any substantial evidence of its benefit, the administration of either propofol or thiopentone to achieve near burst suppression remains popular during temporary clipping.

**Temporary Clipping**

Over two decades ago, temporary clipping of feeder vessels replaced the use of global hypotension as a means of reducing the pressure gradient across the aneurysm wall during surgical dissection. Good communication between the surgeon and the anaesthetist during this period is of paramount importance.

Anaesthetic recommendation during clipping include:

- Blood pressure maintained at high normal levels, to provide for adequate collateral circulation during periods of clamping;
- Brain protection in some form (e.g. propofol, barbiturates), administered prior to clipping;
- Fi 0₂ increased, possibly to 100%, as the administration of 100% 0₂, coupled with brain protection, may have a beneficial effect during temporary clipping;
- The clamp time should be carefully monitored by stopwatch and the surgeon kept abreast of the elapsed time. Guidelines for clamp times vary but a maximum of 15 - 20 minutes is generally recommended.

**Intra-operative aneurysmal rupture**

Intra-operative rupture of an ICA represents one of the major complications that should be anticipated in all cases. Rupture carries a high morbidity and mortality. It can occur at any time during the procedure, and is usually associated with an abrupt increase in the aneurysm’s TMPG. This could be secondary to a sudden increase in BP, a sudden decrease in ICP or due to surgical manipulation or dissection. Rupture during induction, while the skull is closed, carries a worse prognosis than a rupture occurring after the dura
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has been opened. Intra-operative rupture occurs ten times more frequently in previously ruptured aneurysms than in unruptured aneurysms. Bleeding can, in 8% of ruptures, be so severe as to result in haemorrhagic shock.18

The actual anaesthetic management of a rupture varies from centre to centre. The maintenance of normovolaemia should be the primary haemodynamic goal. Surgical management will largely be dictated by the size of the rupture, the stage of the dissection and the ability of the surgeon to occlude the blood vessels proximally and distally by the size of the rupture. In Helsinki, a very aggressive approach has been adopted.18 Cardiac arrest is induced by a rapid IV bolus administration of 12 mg of adenosine into a large vein. During the short period of arrest (± 10 seconds), the operative field is suctioned and temporary clips (so-called “pilot” clips) are placed. Normal rhythm is reportedly returned without any need for medical intervention. It has, however, been recommended that controlled studies are needed to validate the appropriateness of this intervention before making it a recommendation.

Controversy still surrounds blood pressure management during rupture. Wherever possible, temporary vessel occlusion is the preferred technique to gain control of bleeding. When this is not readily possible, mean arterial pressure (MAP) should be transiently decreased to 40 – 50 mm Hg, in order to facilitate surgical occlusion of the rupture. The real danger in the face of continuing major blood loss, if surgical control cannot be rapidly established, is that the combination of hypotension and hypovolaemia can result in profound cerebral ischaemia.5

Emergence

Although fast-tracking techniques aimed at rapid emergence are beneficial in terms of early postoperative neurological assessment, this practice must be balanced against adequate analgesia, if postoperative hypertension and undue agitation are to be avoided.

Analgesic strategies usually include intravenous paracetamol and codeine (see below). Long-acting opioids, such as morphine, should be used with great care in view of their respiratory depressant effect, which can result in hypercapnia and resultant cerebral vasodilation, sedation interfering with neurological assessments and an increased risk of postoperative nausea and vomiting (PONV).

Consideration should be given to the administration of anti-emetic prophylaxis for high-risk groups. Ondansetron is presently favoured.

Postoperative care

Postoperative controlled ventilation should not be considered in good grade patients who were subjected to only brief periods of temporary clipping, as this practice has been shown to adversely affect patient outcome following aneurysm surgery.18 Patients should generally be extubated as soon as they are adequately awake. In patients requiring postoperative controlled ventilation due to complications, or those more severely affected by SAH, propofol sedation should be administered. In addition, continuous ICP monitoring should be initiated. Several centres recommend the addition of jugular bulb saturation monitoring, which is now an established, routine monitoring technique in sedated ventilated postsurgical patients in neuro-intensive care.5

Postoperative monitoring should include frequent neurological assessments.1

Patients should be provided with adequate postoperative analgesia. Paracetamol 1 gm should be given by intravenous infusion, starting intra-operatively and continuing 6 to 8 hourly, to provide analgesia and to prevent and treat hyperthermia. Oxycodone 2 to 3 mg given intravenously can be used to supplement analgesia.18

Prophylactic antiepileptic medication should be considered for cases involving temporal or frontal haematomas.

In some centres, such as Helsinki, anxiolysis with benzodiazepines or haloperidol is used.18

Delayed cerebral ischaemia due to arterial vasospasm is one of the major complications of the postoperative period, occurring up to 14 days after the bleed. Special attention must be paid to its prevention and treatment. The maintenance of systolic blood pressure and normo- to hypervolaemia are important preventative measures. In patients at high risk, systolic blood pressure should be maintained above 140 - 160 mm Hg.18 Nimodipine administration may be accompanied by temporary hypotension. The simultaneous administration of etilefrine (Effortil®) 10 to 20 mg orally with nimodipine tablets is one possible solution. The most common vasoactive drugs employed to maintain blood pressure are phenylephrine, dopamine and noradrenaline.

Serum electrolyte balance should be monitored, as hyponatraemia commonly occurs.

Anesthesia for interventional radiological treatment of intracranial aneurysms

Interventional neuroradiology (INR) has seen major developments in the past decade. Presently there is evidence that coiling has itself as the preferred modality for the treatment of posterior circulation aneurysms.22 With the considerable developments that have taken place over the last few years in the field of endovascular technology, the application of interventional radiological treatment has expanded even further.

Radiation safety

For the anaesthesiologist who only occasionally visits the angiography suite, the usual lead apron will probably suffice. However, for those
who are regularly required to provide anaesthesia or sedation in these radiation hazard environments, additional radiation protection by means of a thyroid shield is recommended.22

Radiological vascular access

The interventional radiologist usually selects the transfemoral arterial approach, placing a large 6,0 French gauge sheath. However, in special circumstances, direct carotid or brachial puncture may be done.22

Materials used for embolisation or infusion

Coils are the most commonly employed technique for aneurysm obliteration. Detachable coils are introduced through a microcatheter, using a pusher wire. Once satisfactorily positioned, they are detached either by electrical or mechanical means. Recent advances have included specialised coatings to encourage thrombus formation and epithelial growth. The success rate of occlusion with coils is dependent on the width of the neck of the aneurysm, with a much greater success rate (up to 85%) being achieved in aneurysms with a neck of less than 4mm.22 Other invasive radiological substances are used in aneurysms, although their usage is more commonly associated with the treatment of arteriovenous malformations and tumour embolisations. These substances include:

- Cyanoacrylates (Histoacryl®, B. Braun) are rapidly polymerising adhesives. The polymerisation process is exothermic, resulting in heat liberation into the surrounding tissues during embolisation, and requires immediate catheter withdrawal after cyanoacrylate injection, because of its adhesive nature.
- Onyx® (Microtherapeutics Inc) is a biocompatible liquid embolic agent consisting of polyvinyl alcohol particles (Contour®, Boston Scientific). Unlike the cyanoacrylates, Onyx® is nonadhesive and the catheter is left in place as the controlled injection and filling of the vascular abnormality takes place over several minutes.

Anaesthetic considerations

Invasive neurological suites are often situated some distance from the operating theatres. This must be taken into consideration when preparing to provide anaesthesia in a remote setting.

In addition to the limited space, the need for the table to be moved frequently requires care in terms of endotracheal tube and intravenous line fixation. The positioning of the anaesthetic machine itself is important to avoid inadvertent disconnections. The imaging equipment must also be mobile around the patient’s head. Further anaesthetic considerations for patients undergoing INR procedures include maintaining patient immobility, and providing haemodynamic manipulation of systemic and regional blood flow and heart rate. As with the clipping of aneurysms, it is important to be prepared for complications that may occur during the procedure. Inadvertent cooling is a problem encountered in the angio suite.

General anaesthesia

Propofol, sevoflurane and desflurane are all used to provide anaesthesia in this environment. Desflurane may have the disadvantage of increasing CBF. Because of the haemodynamic disturbances associated with intubation and extubation, some anaesthesiologists prefer the use of laryngeal mask airways (LMA) with muscle relaxants in appropriately selected patients.22

Sedation

Sedation is occasionally utilised because of the advantage of being able to perform neurological evaluations during the procedure. However, sudden movement of the patients and accidental hypoxaemia tend to make the use of sedation less attractive.

Anticoagulation

To avoid the complications of thrombo-embolic phenomena, these patients should all be anticoagulated with heparin to achieve a 2- to 3-fold increase in Activated Clotting Time (ACT). This is usually achieved by injecting 70 units of heparin per kg. ACT should be monitored hourly and heparin titrated accordingly.

Complications of INR procedures

These may be both rapid and catastrophic, and can be classified into CNS and non-CNS complications.

CNS complications can be divided into either haemorrhagic (aneurysm rupture or vessel dissection) or occlusive (coil displacement into a parent vessel, thrombo-embolic phenomenon and vasospasm) complications.

Non-CNS complications include contrast medium reactions (fatal contrast reactions occur in 1 in 10 000 exposures) and contrast nephropathy, and haematomas at the puncture site, usually in the groin or retroperitoneally.22

Postoperative care of INR patients

A smooth and rapid recovery from anaesthesia, to facilitate neurological examination, is important. Blood pressure maintenance should be approached similarly to that of patients undergoing clipping of aneurysms with vasospasm, requiring elevated systolic pressures. Treatment with nimodipine, likewise, should continue for 21 days. Patients with a large exposure of coils to the parent vessel may require long term aspirin, 75 mg daily for 3 months post procedure. In these cases, heparinisation may have to be maintained in the immediate post-operative period.

The osmotic diuretic effects of contrast medium should not be overlooked, and adequate hydration must be maintained. PONV
is also a problem that should be actively managed, and may be precipitated by both contrast and anaesthetic agents.

Careful neurological evaluations must be performed continuously to identify neurological deterioration as early as possible.

**Cost effectiveness of clipping versus coiling of intracranial aneurysms**

A study was recently undertaken to compare the clinical outcomes, resource consumption, and cost-effectiveness of endovascular treatment vs. surgical clipping in a developing country.23

The study was conducted prospectively from January 2004 to June 2007. Of the patients with ruptured intracranial aneurysms, 24 were treated with interventional coils and the remainder by clipping. A modified Rankin scale was utilised to measure clinical outcome at 6 months, while the total cost of treatment related to all aspects of the inpatient stay were evaluated in both groups.

The average age of the patients in the endovascular group was 38 years, whereas, in the surgical group, it was 45 years. The majority of patients (43) were classified as grades 1 and 2. 18 received coils, and 25 were clipped. Clinical outcomes were similar in both groups. The average total cost for patients undergoing coiling was $5 080, and the total cost with surgical clipping was $3 127.

The higher cost of consumables needed for coiling was not sufficiently offset by shorter hospital stays, and proved the more expensive treatment option without any additional benefit in terms of outcome. However, the lack of outcome benefit, as assessed in such a small number of patients, should be viewed with scepticism. One should rather look to larger clinical trials, such as the ISAT study, when considering outcome-related issues.

**Conclusion**

SAH remains a devastating disease, affecting many other organs in addition to the central nervous system. The main aim of therapy is to prevent rebleeding by either clipping or coiling the aneurysm. Vasospasm is a major contributor to postoperative morbidity and mortality in patients with SAH, and should be actively sought and aggressively managed. Anaesthesiologists have a very important role to play in the overall management of these patients.

**References:**