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Anaesthetic considerations for interventional neuroradiology

M. K. Varma[1]*, K. Price[1], V. Jayakrishnan[2], B. Manickam[1] and G. Kessell[3]

[1]Department of Anaesthesia and Intensive Care and [2]Department of Neuroradiology, Newcastle General Hospital, Newcastle upon Tyne NE4 6BE, UK. [3]Department of Anaesthesia, James Cook University Hospital, Middlesbrough TS4 3BW, UK

**Corresponding author. E-mail: varma.mk@doctors.org.uk*

In the past decade, the neuroradiological diagnosis and treatment of cerebrovascular diseases has undergone significant advances. With the introduction of varying diagnostic and interventional neuroradiological techniques and advances in the materials used for endovascular treatment, increasingly complex diagnostic and therapeutic neuroradiological procedures are being performed on extremely sick patients. As the interventional neuroradiology field expands, the neuroanaesthetist will become more involved in management of patients undergoing neuroradiological procedures. This produces challenges for the neuroanaesthetist, and understanding the anaesthetic implications of the current developments in neuroradiology is important in the management of these patients. This review provides an overview of diagnostic and therapeutic neuroradiological procedures, with special reference interventional neuroradiology, and the anaesthetic management of patients undergoing these procedures.

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Neuroradiological techniques and expertise in the diagnosis and treatment of diseases of the central nervous system (CNS) have undergone significant advances in the past decade[4 11 12] and have introduced new diagnostic and therapeutic radiological procedures. Interventional neuroradiology (INR) or endovascular neurosurgery, a hybrid of traditional neurosurgery and neuroradiology, has emerged as a speciality and has established its role in the management of a variety of neurosurgical conditions, particularly neurovascular diseases. INR can be broadly defined as treatment by endovascular access for the purpose of delivering therapeutic drugs and devices.

The number, variety, and complexity of conditions treated using this route is increasing and this creates challenges for the anaesthetist involved in such procedures. The anaesthetist has a crucial role in facilitating neuroradiological procedures, and this requires an understanding of specific neuroradiological procedures, their potential complications, and their management.

Procedures amenable to INR can be broadly classified on the basis of the aim of treatment.

(a) Closing or occluding procedures: for example, embolization of aneurysms, arterio-venous malformations (AVM) and fistulae of the brain and spine, preoperative embolization of vascular tumours such as meningiomas, temporary or permanent occlusion of arteries intra- or extra-cranially.

(b) Opening procedures: for example, treatment of vasospasm or stenosis by angioplasty and stenting, chemical and mechanical thrombolysis in stroke.

The most common INR procedures in the UK are endovascular treatment of aneurysms, AVM, and preoperative embolization of tumours.

Imaging technology

Neuro-angiography and intervention requires high-resolution fluoroscopy and high-speed digital subtraction angiography (DSA).[24] To remove bone shadows and other non-vascular structures from the images, a scout film is taken before each sequence of fluoroscopy. The scout film serves as a mask, which is subtracted by the computer from all subsequent images so that only vessels opacified by contrast are visible. To facilitate placement of superselective catheters into the distal circulation, a technique called *road mapping* is used. To make a road map, a bolus of contrast is injected into the circulation from the guide catheter (e.g. internal carotid or vertebral artery) to obtain an image of the vascular anatomy. The computer then superimposes this image onto live, bone-subtracted fluoroscopy so that the radiologists can see the progress of radio-opaque microcatheter (especially the tip) against the road map (Fig. 1). Good-quality road maps are dependent on the patient being motionless.

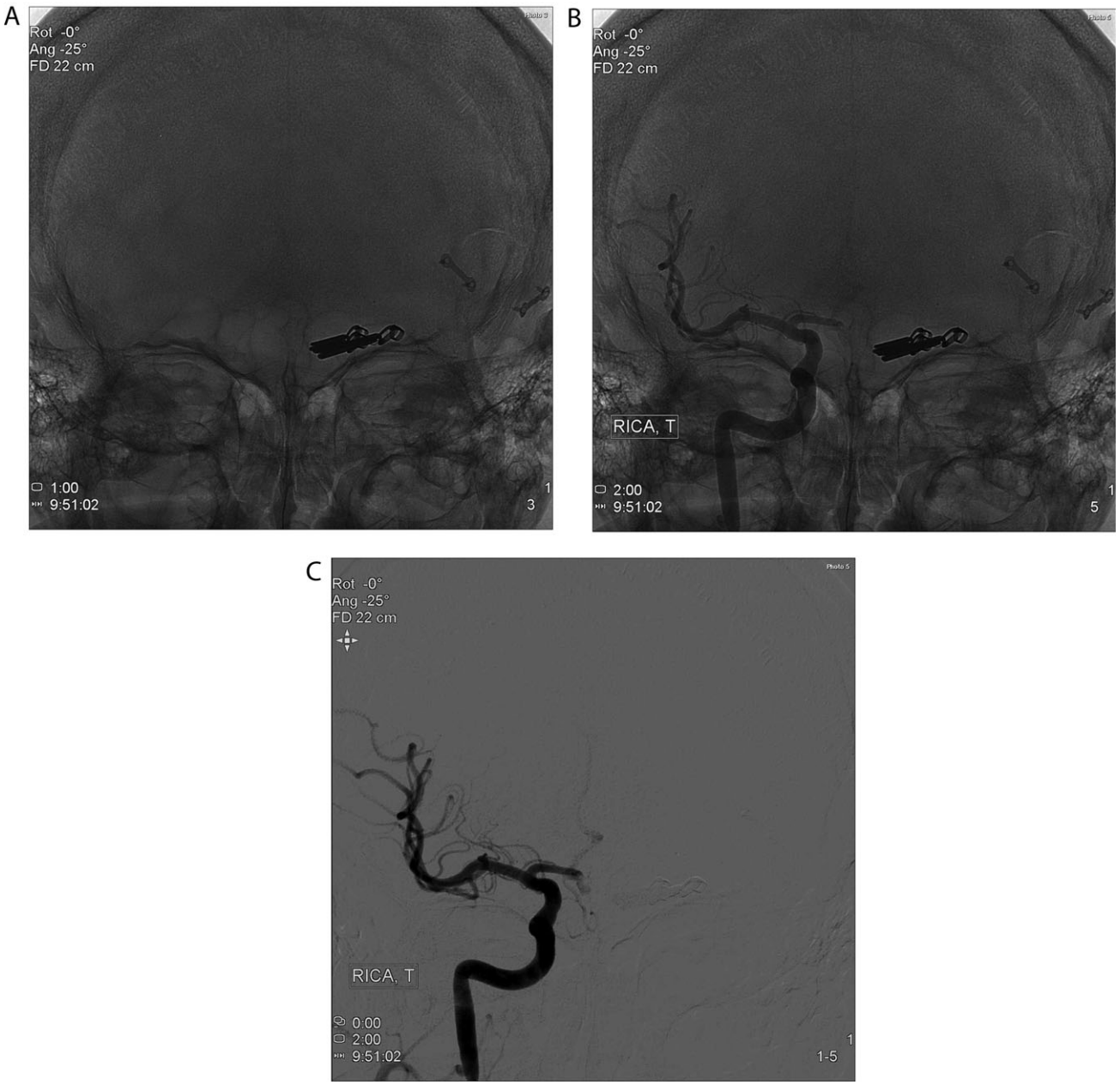

Fig 1 (A) An anterioposterior scout film showing bone. This image is used as the 'mask'. (B) The same view showing contrast injected through the coaxial carotid catheter. (C) Subtraction of mask image (A) from (B) results in the 'roadmap'. The digital image is superimposed on live fluoroscopy which will reflect the course the microcatheter takes as it is advanced distally.

Radiation safety

Personnel working in the neuro-interventional room have the risk of exposure to ionizing radiation. The sources of radiation in the neuroradiology suite includes: direct radiation from the X-ray tube, leakage radiation through the collimators and protective shielding, and scatter radiation that is reflected from the patient and the surrounding area. It is important to realize that DSA delivers considerably more radiation than fluoroscopy. Ionizing radiation follows the inverse square law, that is, the radiation exposure drops off proportional to the square of the distance from the source. Therefore, activity near the head of the patient should be kept to a minimum during fluoroscopy, and the use of extension tubing is required for infusion and monitoring lines. Radiation exposure should be as low as reasonably achievable. Regulatory agencies publish annual allowable limits for maximum exposure for health-care workers.

All personnel working in the room should wear protective lead aprons and thyroid shields throughout the procedure.[33] In some endovascular suites, there are facilities for the anaesthetist to monitor the patient from a distance, normally from an adjoining console area. If this is not available and the anaesthetist is in the same room as the

procedure, they should sit as far as away from the patient as possible during the procedure. Clear lead screens can be used to reduce exposure further.

Radiological vascular access and methods

INR usually involves introducing catheters into the arterial circulation of the head, neck, or spine. The transfemoral arterial approach is usually used, although direct carotid or brachial puncture may be used in special circumstances. For diagnostic angiography, the femoral puncture site is infiltrated with local anaesthetic and a large introducer sheath, usually 6.0 French gauge (FG), inserted into the femoral artery. Through this introducer, an end-hole catheter (4.0–6.0 FG) is then manipulated, under fluoroscopic control, into the carotid or vertebral arteries. A 1.2–2.8 FG superselective microcatheter is introduced through the guide catheter into the cerebral circulation. The superselective catheter can be used to deliver drugs or embolic agents. Modified microcatheters are used for balloon angioplasty and stenting of intra- and extra-cranial vessels.

Transfemoral venous access can be used to reach the dural venous sinuses and the abnormal communication in some types of arterio-venous fistulae (AVF). Direct percutaneous puncture can be used for access to superficial venous malformations involving the head and neck outside the brain.

Materials used for embolization or infusion

The nature of the disease, purpose of embolization, size and penetration characteristics of the embolic material, and permanency of occlusion are all taken into consideration when choosing an embolic agent (Table 1).

Coils

The coils most commonly used for occlusion of aneurysms are detachable or retrievable coils. The basic principle is that it can be advanced into position through a microcatheter using a pusher wire to which the coil is attached. The coil is not detached from the pusher wire until the operator is satisfied with coil placement (Fig. 2). If the coil position is suboptimal, it can be retrieved and redeployed, or removed and replaced by a more appropriate coil. The coils used are usually made of platinum. After satisfactory placement of the coil in the aneurysm, the coil is detached from the pusher wire. Common deployment methods are: (a) electrical—for example, Guglielmi detachable coil (GDC) (Boston Scientific, USA), a platinum coil fused to a stainless steel pusher wire; (b) mechanical—for example, Cook coil (Cook, Europe); and (c) thermal—for example, Micrus endovascular coil (Micrus Endovascular, USA). Recent advances include the development of bioactive coils which are coated with materials (e.g. polyglycolic acid) that promote thrombus formation and endothelial growth (e.g. Matrix Coils—Boston Scientific).

Table 1 Materials used for embolization or infusion

Solid embolic agents: coils, PVA particles, detachable balloons, and gelfoam
Liquid embolic agents: NBCA, EVOH (Onyx^{TM})
Thrombolytic/antiplatelet agents: tissue plasminogen activator, streptokinase/urokinase, abciximab (Reopro), and aspirin
Vasodilators: nimodipine, nicardipine, verapamil, papaverine, and nitrates
Chemotherapeutic agents for tumours

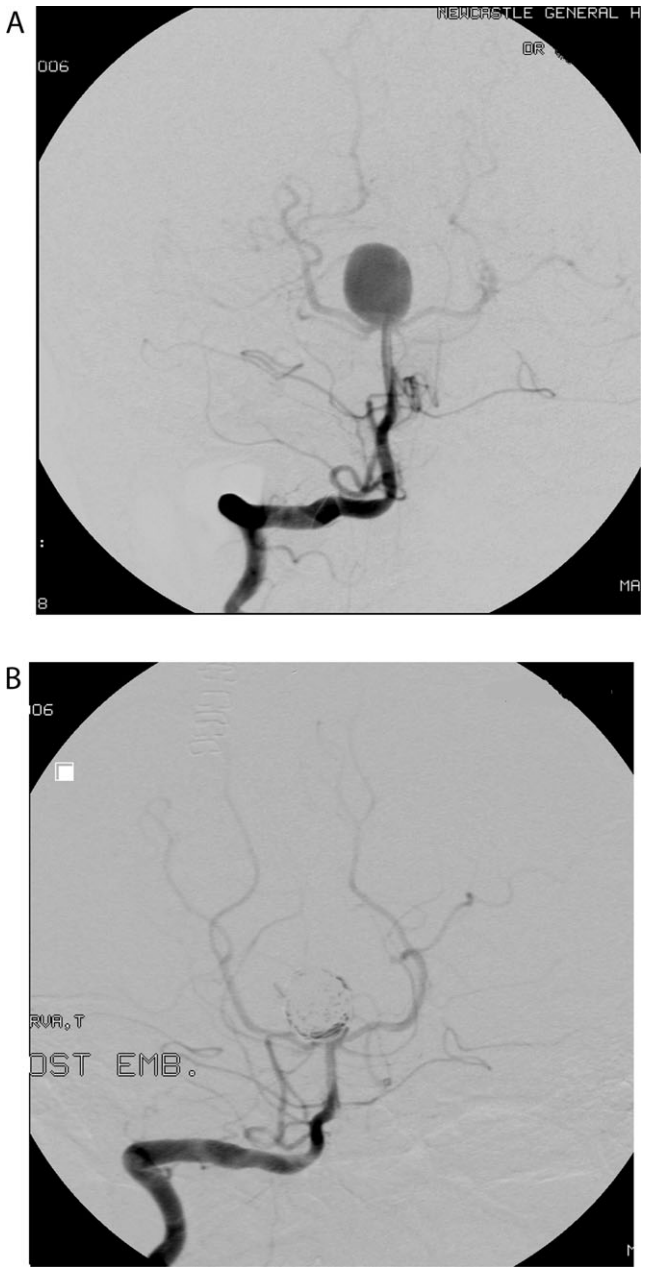

Fig 2 (A) Saccular aneurysm at basilar artery bifurcation. (B) Post-embolization of saccular aneurysm at basilar artery bifurcation.

Cyanoacrylates (Histoacryl, Braun)

Cyanoacrylates are rapidly polymerizing adhesives. The polymerization process is exothermic, which results in heat liberation into the surrounding tissues during embolization. Because of its adhesive properties, the catheter has to be withdrawn immediately after cyanoacrylate injection to avoid it sticking.

Onyx liquid embolic system (Microtherapeutics Inc., USA)

Onyx is a biocompatible liquid embolic agent consisting of ethylene vinyl alcohol copolymer (EVOH) dissolved in dimethyl sulfoxide. Micronized tantalum powder is added to the polymer providing contrast for fluoroscopy. It solidifies through the process of precipitation. Precipitation of onyx begins immediately after injection, creating a skin, which solidifies from the outside in. Precipitation of onyx does not produce heat. Since onyx is non-adhesive, the controlled injection and filling of the vascular abnormality can take place over several minutes, and concurrent angiography can be performed with the catheter left in place. The perceived advantages of Onyx are its ability to reach difficult anatomical locations, the ability to penetrate larger number of feeding vessels in one injection, and more precise control when delivering the material (access, handling, delivery, and visibility).

Polyvinyl alcohol particles

Polyvinyl alcohol (PVA) particles (Contour, Boston Scientific) produce temporary occlusion of blood vessels lasting from a few days to weeks and are the preferred agents for preoperative embolization of tumours such as meningiomas. They are also used in some types of vascular malformations and fistulae.

Neuroradiology procedures

Cerebral angiography

Catheter angiography still makes up the majority of workload in the neuroradiology suite, although a lot of diagnostic angiography is now being accomplished using non-invasive techniques such as magnetic resonance angiography (MRA) and computed tomography angiography. Most patients requiring diagnostic cerebral angiography are awake, unless their neurological state dictates the use of general anaesthesia for airway control or to keep them immobile. There should be departmental guidelines to identify those patients requiring sedation or general anaesthesia for cerebral angiography. Patients must understand the importance of lying still during this procedure and that the room will be darkened. Patients should be warned that they might experience a hot sensation in their head and face during injection, or headache due to traction by the catheter or guide wire during manipulation, especially in external carotid artery branches.

Endovascular treatment of cerebral aneurysms

The incidence of cerebral aneurysms in the general population is 1.5–8.0%. Multiple aneurysms exist in 20% of patients diagnosed with aneurysm.[34] There is an increased incidence in first degree relatives, and an estimated lifetime risk of 2–5%.[9] The significant increase in the number of asymptomatic aneurysms diagnosed is most likely a consequence of screening policies. Patients can present with symptoms of subarachnoid haemorrhage (SAH), cranial nerve palsies, seizures, cerebral compression, and hydrocephalus. Cerebral aneurysm is responsible for 77% of acute spontaneous SAH.[34] Patients who survive a SAH have a 4% risk of a further bleed in the first 24 h and a 1% risk per day thereafter. The morbidity and mortality (3%) rates related to embolization of an acute aneurysm are lower than those associated with an untreated acute ruptured aneurysm.

Endovascular coiling can be safely undertaken within hours of aneurysm rupture. The size and configuration of the aneurysm are the key factors with regards to the success of endovascular coiling. Advanced imaging techniques using a three-dimensional view to evaluate the size and neck of the aneurysm sac (Fig. 3) are useful for choosing the technique.

Aneurysmal disease can be classified into three categories: (a) small, $<$12 mm in diameter; (b) large, 12–24 mm; and (c) giant, $>$24 mm. Complete thrombosis can be achieved in 57–85% of aneurysms with a neck diameter $<$4 mm.[26 64] The total occlusion rate of aneurysms with

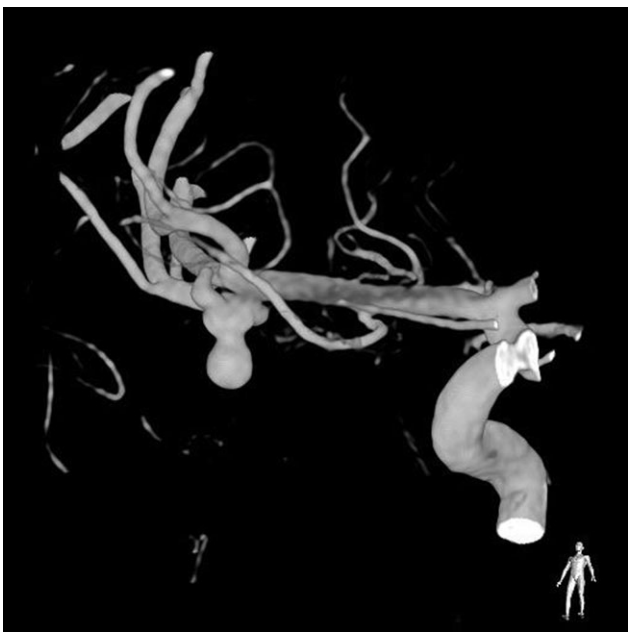

Fig 3 Cerebral angiogram three-dimensional reconstruction showing aneurysm at middle cerebral artery bifurcation.

neck diameter >4 mm is only 15–35%.[26 64] The incidence of re-bleed from treated aneurysms is reduced from approximately 30% to 4% over the first 6 months.[30 50] In 100 patients followed over 2–6 yr, the subsequent rate of haemorrhage was 0% for small aneurysm, 4% for large aneurysms, and 33% for giant aneurysm.[40]

International Subarachnoid Aneurysm Trial and its implications

The International Subarachnoid Aneurysm Trial (ISAT) funded by the UK Medical Research Council has shown that patients with SAH World Federation of Neurosurgeons (WFNS) grades 1 and 2, with small aneurysms in the anterior circulation, have better clinical outcome after endovascular coiling than surgical clipping.[37] One year follow-up in 1594 patients has shown that, overall, 27.2% had died or were dependant (30.6% after surgical clipping and 27.3% after coiling). This represents a 22.6% relative risk reduction and 6.9% absolute risk reduction in morbidity and mortality in patients who underwent endovascular coiling. Overall, case mortality rates were similar between the two groups, with 10.1% and 8.1% in the neurosurgical group and the endovascular groups, respectively. In posterior circulation aneurysms, endovascular treatment has established itself as the preferred modality of treatment.

The ISAT results have produced a change in treatment policy for aneurysmal SAH in most institutes in the UK, and endovascular treatment is generally considered as the first option. This has resulted in considerable increase in activity within the neuroradiology departments. There have been many modifications in endovascular technology aiming to achieve safer, more durable treatment of a large proportion of aneurysms, particularly those with a relatively wide neck where complete occlusion is more difficult and coil compaction and recanalization is more common. Modifications include: coils with more complex shapes, remodelling the neck of the aneurysm using balloon catheters (a non-detachable balloon catheter is deployed across the aneurysm neck and balloon inflated when coils are deployed in the aneurysm, thus preventing prolapse into the parent vessel and allow tighter packing) and the availability of stent-assisted coil embolization (a self-expandable stent is deployed across the aneurysm and then the microcatheter is manipulated through the stent mesh into the aneurysm remnant and coils deployed sequentially occluding the remnant).[28] Surgical clipping may be required for aneurysms with very difficult angiographic anatomy, such as very wide neck aneurysms, vessels arising from or in close relation to the aneurysmal neck, difficult vascular access, or an associated large haematoma.

Patients, with aneurysmal SAH, should be monitored for increased intracranial pressure (ICP), cerebral ischaemia, and hydrocephalus. Patients with a ventricular drain are more prone to transmural pressure changes and increased risk of re-bleed with raised arterial pressure. I.V. nimodipine is given at diagnosis to protect against cerebral ischaemia from vasospasm. General anaesthesia may be preferred for coiling of cerebral aneurysm as the lack of movement and physiological stability during the interventional procedure reduce the incidence of perforation. Aneurysm perforation occurs in 2.3–3% of ruptured aneurysms treated with coiling (Fig. 4).[40] The risk of perforation of a previously unruptured aneurysm is <0.5%.[17 20 23 38 42 44 62] Thrombus can form on the catheter, guide wire, or coil during or after the coil placement. The overall incidence of thromboembolic complication is 2.5–5%.[51] Coil unravelling and coil fracture are also reported. Parent artery compromise due to coil displacement occurs in 2.5% of patients.[51]

Recanalization of coiled aneurysms remains a significant problem, and generally the larger the aneurysm the higher the risk of recanalization. Follow-up angiography is recommended for all coiled aneurysms, usually at 6 months and 2 yr. In future, MRA is likely to be used for this. Surface active and bioactive coils have been developed to address the problem of recanalization, but their benefit is yet to be proven.

Embolization of AVM

The two main types of vascular malformations amenable to endovascular treatment are parenchymal cerebral AVM and AVF.

Cerebral AVM consist of a vascular convolute with a nidus that is fed by one or more arteries and drained by one or more veins. Capillary vessels are typically missing and arteries and veins are connected by arterio-venous shunts. The malformations are presumed to be congenital lesions resulting from abnormal vascular malformation during embryonic development. Their prevalence, as determined by autopsy, is 0.5%.[41] Approximately 10% of patients with AVM have intracranial aneurysms.

Patients can present with spontaneous haemorrhage, seizures, or with neurological symptoms due to local

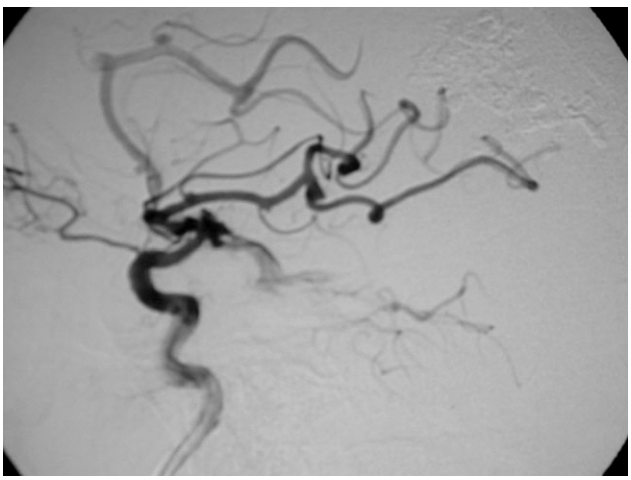

Fig 4 Contrast extravasation from the fundus of posterior communicating artey aneurysm.

ischaemia caused by steal phenomena or venous hypertension.[21] The risk of haemorrhage after diagnosis is approximately 2–4% per year.[48] There are three treatment options: surgical resection, embolization, or stereotactic radiosurgery. On its own, embolization is curative in about 20% patients, usually small lesions with only one or two feeding arteries. Embolization is often performed to reduce the nidus size before surgical resection or radiosurgery.[63] AVM with multiple feeding arteries may require several injections and staged treatment. Reported mortality and morbidity rates after embolization of AVM are 1–1.6% and 5–7%, respectively.[63]

AVF consist of a direct connection between an artery and a vein. Pial AVF are usually congenital. This type of shunt is found in the Vein of Galen malformations, carotid-cavernous fistulas, and spinal AVF. Patients may present with symptoms due to cardiac failure, mass effect, bruit, or seizures. Dural AVF are acquired after trauma and are usually high-flow. They can also occur as a consequence of venous sinus thrombosis and venous hypertension.[47] Multiple dural arterial feeders are typical of dural AVM and this is thought to be due to thrombosis and subsequent recanalization of major dural sinuses.

Endovascular treatment is successful in 85–95% patients, but recurs in 2–9%.[22] In general, transarterial embolization is performed for high-flow single-hole fistulas with balloons, coils, stents, or *N*-butyl cyanoacrylate (NBCA). General anaesthesia is preferred for embolization of AVM, as it facilitates visualization of structures and prevents patient movement. Temporary apnoea and a Valsalva manoeuvre can be applied to improve visualization. Controlled hypotension and flow arrest are easily achieved, and may be required to reduce the flow across AVM.

The exact mechanism of haemodynamic complications after treatment of AVM remains controversial.[66] Normalizing perfusion pressure in parts of vessels with impaired autoregulatory capacity after embolization or surgical resection of a large, high-flow AVM is thought to cause normal perfusion pressure breakthrough. As AVM feeding arteries supply a variable amount of normal brain, abrupt restoration of normal systemic pressure to a chronically hypotensive vascular bed may overwhelm the autoregulatory capacity and result in parenchymal haemorrhage. Therefore, it is desirable to maintain arterial pressure about 15–20% below the patient's normal level after the procedure.[53 54] Alternative theories to explain haemodynamic complications include occlusion of the draining venous system in the brain surrounding the AVM, followed by passive hyperaemia and stagnation in the feeding artery.[1 68] Embolization of glue into the draining vein may result in venous outflow obstruction and pulmonary glue embolization.

Tumour embolization

Preoperative embolization is used for meningioma, glomus tumour, and juvenile nasopharyngeal angiofibroma. The primary goal of embolization is to reduce tumour vascularity before surgery to minimize blood loss and to facilitate dissection. This is best achieved with PVA particulate embolization. The procedure is usually performed with the patient awake.

Carotid occlusion test

The carotid occlusion test is primarily used to test the adequacy of the cerebrovascular collateral circulation before electing to occlude the carotid artery, by showing whether the patient can tolerate temporary or permanent occlusion. This may be necessary during surgery for tumours involving the internal carotid artery, either at skull base or intracranially, or for giant internal carotid and vertebrobasilar aneurysms. Combining the carotid occlusion test with controlled hypotension (10–20% of baseline) increases the predictive value of the test.[56] The most common complications during the performance of occlusion test are bradycardia, hypertension, and loss of consciousness. The patient must be awake for the procedure, as continuous neurological evaluation is required to assess the effects of occlusion.

Superselective anaesthesia functional examination and Wada test

The Wada test consists of behavioural testing after the injection of an anaesthetic agent, such as sodium amobarbital or sodium methohexital, into the internal carotid arteries. The test is conducted with the patient awake, to determine the dominant side for vital cognitive functions, namely speech and memory. Typical uses of the test include the lateralization of language abilities before surgery. In surgery for a non-life-threatening condition, for example, epilepsy, this is an important consideration.

Superselective anaesthesia functional examination (SAFE) is an extension of the Wada test. It is carried out before therapeutic embolization, to exclude inadvertent placement of the tip of the catheter proximal to the origin of normal vessels supplying important regions in the brain or spinal cord.[49] The patient should be awake before performing the test. Sodium amytal is injected into the vascular territory planned for occlusion and repeated neurological examination is made to exclude any functional involvement.

Anaesthetic considerations

Many INR suites are situated at some distance away from the operating theatre. This is being addressed in newer hospitals, but is still prevalent, with anaesthesia technical support being provided at a distance. Other potential problems include working in reduced light, poor access to the patient, and concerns of ionizing radiation. Anaesthetic considerations when providing anaesthesia to patients

undergoing INR procedures includes maintenance of patient immobility and physiological stability, manipulating systemic and regional blood flow, managing anticoagulation, and treating sudden unexpected complications during the procedure. The medical management of critically ill patients during transport to and from radiology suites and smooth and rapid recovery from anaesthesia to facilitate neurological examination is equally important.[65 67]

Pre-assessment

Detailed patient evaluation and understanding of the underlying neuropathology are essential. In addition to the normal pre-anaesthetic evaluation, a patient undergoing a neuroradiology procedure requires a careful neurological examination to identify any deficits present, with special attention to Glasgow Coma Score. Baseline arterial pressure and cardiovascular reserve should be evaluated, as should renal insufficiency. As anticoagulation is employed during most procedures, evaluation of coagulation is important.

A note should be made of patient's previous experience with angiography, protamine allergy, and contrast reaction. Iodine and shellfish allergies are particularly important. It should also be borne in mind that arthritis of neck, back, or other joints will influence the patient's ability to lay supine and the potential for airway compromise with sedation. Patients should continue to take their usual prescribed medications. Sedative premedication should be avoided.

Anaesthetic technique

Choice of anaesthetic technique varies between centres with little data to support any specific technique. However, the needs of the neuroradiologist and the procedure should be considered in choosing the anaesthetic technique.

General anaesthesia

Most neuroradiologists prefer general anaesthesia as opposed to sedation for optimal imaging as this provides an immobile patient with improved image quality, patient comfort, and better control of the respiratory and haemodynamic profile. The disadvantages are the inability to perform neurological assessment intraoperatively and the consequences of endotracheal intubation and extubation producing hypertension, coughing or straining which can lead to raised ICP.

With most anaesthetic agents (propofol, desflurane, and sevoflurane), anaesthesia can be rapidly induced with minimum haemodynamic changes, the depth rapidly controlled, and a smooth and rapid emergence obtained. A recent study, comparing the speed of recovery after maintenance of anaesthesia for neuroradiology with sevoflurane or propofol, found that sevoflurane was associated with more rapid recovery.[16] The limitations of the study were that the intraoperative depth of anaesthesia was not controlled. The advantage of sevoflurane over desflurane may be that higher concentrations of desflurane cause increased cerebral blood flow and loss of autoregulation.[6] In an experimental porcine model of raised ICP, desflurane at 0.5 and 1 MAC were associated with more cerebral vasodilatation and higher ICP at normocapnia compared with isoflurane or sevoflurane.[36] However, the difference in ICP was less evident during hyperventilation. These findings were not consistent in a human study.[55]

Nitrous oxide is preferably avoided, as there is risk of enlargement of micro air bubbles during injection of contrast or irrigation fluid.

The laryngeal mask airway (LMA)* may be used as an alternative to endotracheal intubation for the management of the airway. It allows airway control with less haemodynamic stress and for a smooth emergence from anaesthesia. Muscle relaxation and controlled ventilation can be achieved with the LMA provided there is appropriate patient selection.

Sedation

It is important that for safe sedation, the operator should not be responsible for sedation. Sedation with propofol is used widely. Dexmedetomidine has been used for sedation.[32] Patients sedated using dexmedetomidine are arousable and co-operative when stimulated. A lack of respiratory depressant effect is another advantage.[32] It has been used in patients undergoing awake craniotomy in which neuropsychological testing was required[2 7 32] and in endovascular embolization of AVM.[13]

The benefits of sedation are that it is easier to perform neurological testing repeatedly and the avoidance of haemodynamic changes associated with intubation and emergence. The disadvantages are an unprotected airway with the risk of aspiration and the potential for hypoxaemia and hypercapnia if used inappropriately. Sudden patient movements and delays in managing a neurological emergency may also occur.

Conduct of anaesthesia

The anaesthetic machine is best located opposite the neuroradiologist and towards the patient's feet. This position keeps it out of the way, and imaging equipment can move freely around the patient's head. Patient positioning is especially important, if the procedure is to be performed under monitored anaesthesia care or conscious sedation.

Secure i.v. access should be available to allow drug and fluid administration at maximal distance from the image intensifier during fluoroscopy. Infusions of drugs, such as

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anticoagulants or remifentanil, should be given through a separate cannula.

Standard monitoring is required, regardless of anaesthetic technique. For intracranial procedures and postoperative care, an arterial line can facilitate pressure monitoring and blood sampling. If arterial cannulation is difficult, then a side port of the femoral artery introducer sheath can be used to monitor the arterial pressure. Using a coaxial or triaxial catheter system, arterial pressure at the carotid artery, vertebral artery, and the distal cerebral circulation can be measured. A coaxial catheter frequently underestimates the systolic and overestimates the diastolic arterial pressure. Deliberate hypertension for occlusion and vasospasm, or hypotension, to slow blood flow in the feeding artery of an AVM before glue injection, may be required during interventional procedures. There should be sufficient slack in all monitoring lines, i.v. lines, and airway connections as the patient table may need to move back and forth during imaging and coiling.

Catheterization of the bladder is required for most procedures. This assists in fluid management and aid patient comfort. A significant volume of heparinized flush solution and radiographic contrast is often used, and administration of diuretics such as mannitol and furosemide may be required intraoperatively.

Hypothermia can occur in the neuroradiology suite, and measures should be taken to keep the body temperature near normal and core temperature measured.

Anticoagulation

Careful management of coagulation is required to prevent thromboembolic complications during and after the procedure. In general, after a baseline activated clotting time (ACT) is obtained, i.v. heparin (70 IU kg^{-1}) is given to prolong ACT by two to three times. ACT is monitored at least every hour and if required additional dose of heparin given. A heparin infusion may be continued after the procedure to protect against both thrombogenic effects of endothelial trauma and the inherently thrombogenic nature of the materials instilled, which can cause retrograde thrombosis in embolized vessels.

The sustained reduction in morbidity and mortality by antiplatelet agents in coronary thrombosis patients undergoing angioplasty/stenting or thrombolysis has led to interest in their use for endovascular procedures of the CNS.[27 58]

Complications of interventional neuroradiological procedures

Complications during the INR procedures (Table 2) can be rapid and catastrophic. There should be good communication between the neuroradiologist, anaesthetist, and the radiographer for the prompt management of complications that may occur. The primary responsibility of the anaesthetist is for the airway and gas exchange. It is important to know whether the complication is occlusive or haemorrhagic as these require a different approach for successful management.

Table 2 Complications of interventional neuroradiological procedures

CNS complications
Haemorrhagic
Aneurysm perforation
Intracranial vessel injury, dissection
Occlusive
Thromboembolic complications
Displacement of coil into parent vessel, coil fracture
Vasospasm
Non-CNS complications
Contrast reactions
Contrast nephropathy
Haemorrhage at the puncture site, groin haematoma, retroperitoneal haematoma

Haemorrhagic complications

Haemorrhage is often accompanied by an abrupt rise in mean arterial pressure. Immediate reversal of heparin may be required (1 mg protamine for each 100 units of heparin given) and lowering of the systemic arterial pressure. Pa_{CO_2} should be maintained between 4.5 and 5.0 kPa and mannitol (0.25–0.5 g kg^{-1}) may be given to reduce cerebral oedema. Aneurysm perforation is usually treated by packing the defect with coils. Emergency craniotomy and clipping of aneurysm may be required if coiling fails. Patients may develop acute hydrocephalus secondary to new SAH necessitating transfer to theatre, for ventricular drainage.

Occlusive complications

In the event of occlusion, the arterial pressure should be raised to increase collateral blood flow and maintain normocarbia. Angiographically visible thrombus may be treated by mechanical lysis using a guide wire or local infusion of saline. Thrombolytic agents are commonly used to treat intraprocedural thrombosis, but results have been mixed. The use of local intra-arterial tissue plasminogen activator has shown to achieve recanalization rate of 44%.[31] Antiplatelet agents, such as abciximab (ReoPro), a GPIIb/IIIa inhibitor (i.v. and intra-arterial), have also shown promising results.[27] Malpositioned coils compromising parent artery are removed by endovascular retrieval and rarely craniotomy may be needed.

Treatment of vasospasm can be either medical (triple therapy: hypertension, hypervolaemia, and haemodilution), pharmacological (papaverine), or by angioplasty. Triple therapy cannot be recommended for prophylaxis of vasospasm, but is often used for symptomatic vasospasm. There is no evidence that outcomes are necessarily better than the natural history of vasospasm would have

produced.[60 61] Risks associated with triple therapy include: pulmonary oedema, myocardial ischaemia, electrolyte imbalance and cerebral oedema.[25 60] Intra-arterial papaverine infusion results in clinical improvement in 25–50% of patients with vasospasm.[39] However, papaverine has a transient effect (up to 24 h) and is associated with side-effects, including monocular blindness, mydriasis, seizures, transient increase in ICP, hypertension, tachycardia, and paradoxical worsening of vasospasm.[19] Early experience with intra-arterial nimodipine and nicardipine to treat vasospasm in a small group of patients was favourable.[3 8]

Angioplasty is widely considered to be the most effective procedure.[10] It is most effective when done early, within 2 h of symptomatic ischaemia, to prevent the transformation of an ischaemic infarct to a haemorrhagic infarct. It is effective in 98–100% of patients and results in clinical improvement in 70–80%. Recurrent spasms after SAH are relatively uncommon after angioplasty. Complications include vessel rupture (2–5%) and re-bleed from an unprotected aneurysm (5%).[10] The procedure is often limited by the size of the vessel involved and is usually not done beyond A1 and MI segments.

Contrast reactions

The most commonly used contrast for INR nowadays is iohexol (non-ionic) with an osmolality of 672 mOsm kg^{-1}. Although fatal reactions occur at the same frequency ionic agents (1:10 000 exposures), non-ionic agents have a lower incidence of mild and moderate reactions.[14 15 35 57] Reactions can be caused by hypertonicity, direct cardiac depression, or idiosyncratic anaphylactoid reactions. For patients with a previous reaction to contrast, pre-treatment with steroids and antihistamines is recommended.[29]

Contrast nephropathy

This is the third most common cause of hospital-acquired renal failure, and accounts for 12% of patients.[46] The risk factors include diabetes mellitus, high dose of contrast, volume depletion, co-administration of nephrotoxic medications, and pre-existing renal disease.[45] A direct correlation between the osmolality of contrast media and nephrotoxicity is well established.[5] Patients with pre-existing renal dysfunction were less likely to develop contrast-induced nephropathy when non-ionic contrast media were used.[52]

To prevent renal complications, perioperative fluid management should be aimed at maintaining normovolaemia, to offset the diuretic effect of the injected contrast. *N*-acetylcysteine, 600–1200 mg twice daily, two doses before and after the procedure has shown significant reduction in the incidence[59] and it is acceptable for use in high-risk patients. Isotonic bicarbonate infusion may also reduce the incidence of contrast-induced nephropathy, by alkanizing renal tubular fluid and thereby minimizing tubular damage.[43] Other agents such as vasodilators (dopamine/fenoldopam), theophylline, calcium channel blocker, and antioxidants (ascorbic acid) have all been tried without any conclusive result.

Postoperative care

All patients who undergo interventional procedures should be cared for in a high dependency unit, unless their neurological condition dictates admission to intensive care. However, most patients after procedures such as particle embolization for tumours can be nursed on the ward. Patients should remain supine until the femoral sheath is removed.

Maintenance of modest hypotension is required post AVM embolization to prevent cerebral oedema and haemorrhage. The mean arterial pressure should be kept 15–20% below the baseline for 24 h.[18] Antihypertensive agents such as labetolol or esmolol, which have minimal effect on cerebral physiology, can be used to control pressure. A mean arterial pressure 20–30% above normal may be required in patients with occlusive conditions or vasospasm to maintain cerebral perfusion pressure. This can be achieved with the use of phenylephrine or norepinephrine. Nimodipine, i.v. or through a nasogastric tube, is used in aneurysmal SAH until the patient can take oral medication and continued for 3 weeks. Most patients receive aspirin 75 mg for 3 months afterwards. Maintenance of heparinization in the post-procedure period is recommended if a large surface area of coil is exposed in the parent vessel, or if an embolic complication was encountered during the procedure.

Postoperative nausea and vomiting can be a problem due to contrast and anaesthetic agents used during the procedure. Maintenance of hydration is important, as there can be a large osmotic diuresis due to hyperosmolar contrast used during the procedure.

Post-procedure ischaemia and swelling from contrast can be symptomatic after procedures performed in the posterior fossa. Continuous neurological observation should be made to identify any new neurological deficit and appropriate intervention undertaken.

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