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Anaesthesia for interventional neuroradiology

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Key points

- The spectrum of cases which are undertaken in an interventional neuroradiology suite is rapidly expanding.
- An appreciation of the underlying pathology and multisystem effects of the disease is needed.
- Cerebral protection strategies must be used.
- The hazards of remote site anaesthesia and ionizing radiation must be appreciated.
- Close monitoring in the post-procedural period is essential to identify any rapidly evolving neurological deficits, indicating potential bleeding or vessel occlusion that may necessitate emergency radiological or neurosurgical intervention.

The scope of interventional neuroradiology has expanded rapidly. Conditions which were previously untreatable or only amenable to open surgical techniques are now being considered for interventional radiological management (Table 1).

Subarachnoid haemorrhage

Subarachnoid haemorrhage (SAH) accounts for about 5% of all strokes and may be due to congenital or acquired conditions, the most common being intracranial aneurysms. Cerebral aneurysms are present in up to 6% of the population.[1] SAH requires a multi-disciplinary approach to management, at a dedicated neurosciences centre.

Patients may present with sudden-onset occipital headache ('thunder clap'). Associated features include nausea and vomiting, neck stiffness, photophobia, focal neurology, deteriorating level of consciousness, seizures, and cardiac arrest.[2] Complications after an SAH include re-bleeding (5–10% in the first 72 h), obstructive hydrocephalus (incidence of 20–30% within 3 days of ictus), and vasospasm (angiographically demonstrated arterial narrowing 3–14 days after SAH). Delayed cerebral ischaemia and vasospasm may be asymptomatic and are associated with a worse outcome after SAH. The mortality rate at 7 days post-SAH is up to 40%.

Other multisystem features include ECG changes (e.g. shortened PR interval, prolonged QTc interval, ST segment changes, and changes to T wave morphology), elevated cardiac enzymes, cardiogenic and neurogenic pulmonary oedema, and sodium disturbances. Patients with suspected diagnosis of SAH should have an urgent non-contrast computerized tomography (CT) scan (sensitivity of 95–100% on first day), and may require a lumbar puncture 12 h post-ictus if CT is negative.

Aneurysms usually develop in the Circle of Willis at sites of vessel branching. The risk of rupture is directly related to the size of the aneurysm, typically classified as small <12 mm, large 12–14 mm, and giant >24 mm.[3,4]

The gold standard for the detection of intracranial aneurysms is four-vessel digital subtraction angiography (DSA). CT angiography (CTA) is more rapid, readily accessible, and less invasive, but the sensitivity and specificity for smaller aneurysms (<5 mm) is lower.[5] Magnetic resonance angiography (MRA) can give more information regarding the cause of the intracranial bleed, but the longer scanning time is of significance in an acutely unwell patient.

Treatment of aneurysmal disease is either by endovascular coiling of the aneurysm or by open surgical clipping. The International Subarachnoid Aneurysm Trial (ISAT) was a multicentre, randomized controlled trial that compared endovascular coiling and neurosurgical clipping of ruptured intracranial aneurysms. The initial findings favoured coiling; the primary outcome (risk of death or dependence at 1 yr) occurred in 23.7% of coiled patients *vs* 30.9% of surgically clipped patients, with an absolute

Table 1 Classification of interventional neuroradiological procedures

Intracranial lesions
Diagnostic angiography
Glue embolization of cerebral arteriovenous malformation
Coil embolization of cerebral aneurysms (elective and emergency)
Embolization of carotid-cavernous fistula
Intracerebral chemotherapy for head and neck tumours
Sclerotherapy of venous angiomas
Balloon angioplasty and carotid artery stenting
Venous stenting
Therapeutic carotid occlusions for giant aneurysms and skull base tumours
Embolization of intracranial tumours
Carotid artery test and therapeutic occlusions for aneurysms and tumours
Stenting of aneurysms
Thrombolysis and thrombectomy after stroke
Treatment of cerebral vasospasm and carotid stenosis with transluminal balloon angioplasty
Extracranial lesions
Embolization of dural arteriovenous malformations, fistulae, and spinal arteriovenous malformation
Vertebral artery stenting
Vertebroplasty and kyphoplasty
CT-guided interventions
Biopsies of tumours and masses
Interventional magnetic resonance imaging
Stereotactic-guided neurosurgery—deep brain stimulation for movement disorders
Implantation of intracranial electrodes for telemetry
Temporal lobe resections for epilepsy

risk reduction of 6.9%. However, long-term follow-up of ISAT patients revealed the need for delayed re-treatment was significantly higher in coiled patients.[5–7] Coiling is the preferred treatment in the majority of aneurysms, especially posterior circulation aneurysms. Clipping may be required if the aneurysm has difficult anatomy such as a wide neck, and there is difficult angiographic arterial access, or if coiling fails.

Endovascular management of aneurysmal disease

Endovascular treatment is achieved by one of two methods—obliteration of the aneurysmal sac using coils with or without stents or on rare occasions occlusion of the proximal parent arteries feeding the aneurysm.[8] The radiologist usually uses a transfemoral arterial approach, with insertion of a femoral sheath followed by a catheter. This is then navigated into the carotid or vertebral artery. A micro-catheter is introduced through this into the cerebral circulation. Typically, detachable platinum coils are advanced into position and the coils deployed into the sac of the aneurysm until occlusion is achieved. Newer hydrocoils are available, which have a coating of synthetic polyalcohol over the platinum coil, which expands within minutes after contact with blood, resulting in good volumetric packing. Other innovations include bioactive coils, which produce an enhanced cellular response stimulating neo-intima formation across the aneurysm neck, thus preventing re-bleeding and re-growth.

Stents (metal mesh devices in the shape of a vessel) can be placed inside the parent artery at the site of the aneurysm to cover the neck of the aneurysm. This helps to keep the coils within the aneurysm in place.

Flow-diverting stents divert blood flow within an artery, thus decreasing the flow within an aneurysm. Placing high strut density stents results in spontaneous thrombosis of the aneurysm, without occluding the parent vessel. However, it must be remembered that there is a high risk of arterial thrombosis, and adequate anticoagulation should be ensured. Pre-procedural testing of platelet inhibition will shortly be expected practice for flow-diverting stents.

Balloon-expandable stents have also been introduced, and are used to assist coil embolization of difficult lesions such as dissecting, fusiform, and wide-necked aneurysms which are unfeasible for simple coiling.

Balloon trapping of an aneurysm involves balloons being placed intravascularly above and below a giant aneurysm.

Manipulation of the aneurysm sac may cause distal thromboembolism and rupture. Indications of rupture in the anaesthetized patient include sudden onset of bradycardia, or hypertension as a result of raised intracranial pressure (ICP). The radiologist may visualize contrast extravasation on screening.[6] Management includes arterial pressure control by deepening anaesthesia, or the use of antihypertensives such as i.v. labetolol. Heparin should be reversed with protamine (1 mg protamine per 100 units heparin given) if requested by the radiologist, and radiological control of the leak should be obtained. If the extravasated blood load is high, the patient may require a CT scan and the insertion of an external ventricular drain (EVD), if there is imminent danger of developing obstructive hydrocephalus. The EVD allows drainage of cerebrospinal fluid should intracranial hypertension develop. Craniotomy may be required for intracranial haematoma evacuation and surgical clipping of the aneurysm. Other complications include vascular occlusion secondary to arterial thrombus, emboli, vasospasm, or misplaced catheter or coils. Management involves increasing collateral flow by increase in arterial pressure to 30–40% above baseline, with or without direct intra-arterial thrombolysis with abciximab (a glycoprotein IIb/IIIa receptor inhibitor). I.V. aspirin is often administered, and the misplaced catheter/coils are removed,[6,8] followed by thrombectomy if indicated.

I.V. aspirin, heparin, and abciximab are administered to reduce the risk of vascular occlusion secondary to thromboembolism, pre-, intra-, and post-procedure at the request of the radiologist. In elective treatment of unruptured aneurysms, at least one dose of aspirin could be administered the day before the coiling, and if stent-assisted coiling is envisioned then aspirin and clopidogrel should be given 3–5 days before the procedure. Post-procedure, if a stent has been placed, patients may be prescribed aspirin 75 mg daily for life and clopidogrel 75 mg daily for 3 months to decrease the incidence of thromboembolic complications. Platelet function testing is also being used in some centres to identify patients who could benefit from higher dosing, balancing the risks of thrombosis and antiplatelet therapy.

Management of vasospasm has moved away from the traditional triple H therapy—hypertension, hypervolaemia, haemodilution—to hypertension and euvolaemia. Arterial pressure targets in secured aneurysms aim for a systolic arterial pressure of 160–180 and 140–160 mm Hg in unsecured aneurysms.[8] Nimodipine, a calcium channel antagonist, is given to all SAH patients for 21 days to reduce the risk of delayed cerebral ischaemia and poor outcome. If vasospasm occurs during coiling, intra-arterial nimodipine can be administered, or balloon cerebral angioplasty can be performed.[8]

Arteriovenous malformations

These are congenital abnormalities, which commonly consist of abnormally large and complex vessels, often containing fistulae

with multiple arterial and venous supplies.[9] They shunt blood from the arterial to venous system and can bleed. Patients may present with headaches, intracranial haemorrhage, and seizures. Treatment includes open surgery or embolization.

Endovascular treatment of arteriovenous malformations

Arteriovenous malformations (AVMs) are treated by glue embolization of fistulae and feeding arteries, by injecting fast setting embolic material or coils into the nidus of the AVM. Cyanoacrylate adhesives are polymerizing adhesives, which solidify when they come into contact with ionic solutions, that is, blood. Ethylene vinyl alcohol co-polymer (trade name Onyx) is a non-adhesive polymer that solidifies through the process of precipitation, allowing for controlled injection and filling of the vascular abnormality over several minutes.[4,8] The arterial pressure may need to be manipulated to facilitate deposition of embolic material within the nidus of the AVM. Complications include embolization of glue into the draining vein, resulting in venous outflow obstruction, cerebral haemorrhage, and pulmonary circulation glue embolization. Embolic material may also embolize normal brain arteries. Abrupt restoration of normal systolic pressure to a chronically hypotensive vascular bed may overwhelm the cerebral autoregulatory capacity and result in parenchymal haemorrhage or swelling, thus the mean arterial pressure should be kept to 20% below baseline.[4,8] Severe post-procedural headache may be indicative of bleeding. Steroids may be administered prophylactically post-procedure to reduce the incidence of perinidus oedema. These patients often need to have multiple procedures to achieve complete obliteration of the AVM.

Carotid artery stenosis

Patients who have symptomatic internal carotid artery stenosis (>70%) who are considered high risk for general anaesthesia and open surgery may be considered for endovascular treatment by angioplasty and stenting under local anaesthesia. This allows for constant assessment of neurology during the procedure and preservation of cerebral autoregulation. Deployment of the stent can cause parasympathetic stimulation—bradycardia and hypotension. There is also a risk of hyperperfusion syndrome and careful arterial pressure control is needed after stenting that may necessitate i.v. antihypertensive treatment. Therefore, these procedures are usually performed with anaesthetic presence to manage haemodynamic disturbances.[6,10] Other complications include vessel occlusion, thromboembolism, dissection, and perforation (Fig. 1).

Hyperacute ischaemic stroke

CT-guided i.v. recombinant tissue plasminogen activator (rtPA) administered within 4.5 h of stroke onset is currently considered the definitive treatment for hyper acute ischaemic stroke. However, in those patients in whom rtPA therapy has failed, or when the i.v. rtPA treatment window has passed, i.v. rtPA can also be given as a bridging therapy while other endovascular options are considered, such as intra-arterial rtPA. Intra-arterial therapy should be undertaken within 6 h of the onset of neurological symptoms[11] for anterior circulation strokes, and within 24 h for posterior circulation strokes.[8]

Administration of intra-arterial rtPA involves cerebral angiography to localize the occluding clot, navigation of a micro-catheter adjacent to the clot, and injection of intra-arterial rtPA. This may be combined with mechanical clot retrieval systems such as aspiration/suction systems, clot retriever devices, ultrasonography, snare, or laser devices with or without transluminal angioplasty and stenting.

A recent consensus statement has been issued by the Society of Neuroscience in Anesthesiology and Critical Care (SNACC) on the anaesthetic management of endovascular treatment of acute ischaemic stroke.[12] It recommends that preoperative assessment of patients undergoing endovascular treatment for acute ischaemic stroke should be performed as quickly as possible and should not delay treatment. Intra-arterial thrombolysis should be performed within 6 h, and thrombectomy within 8 h of symptom onset. In cooperative patients, the use of local anaesthesia with conscious sedation should be performed. However, rapid conversion to general anaesthesia may be necessary. General anaesthesia is preferred in uncooperative or confused

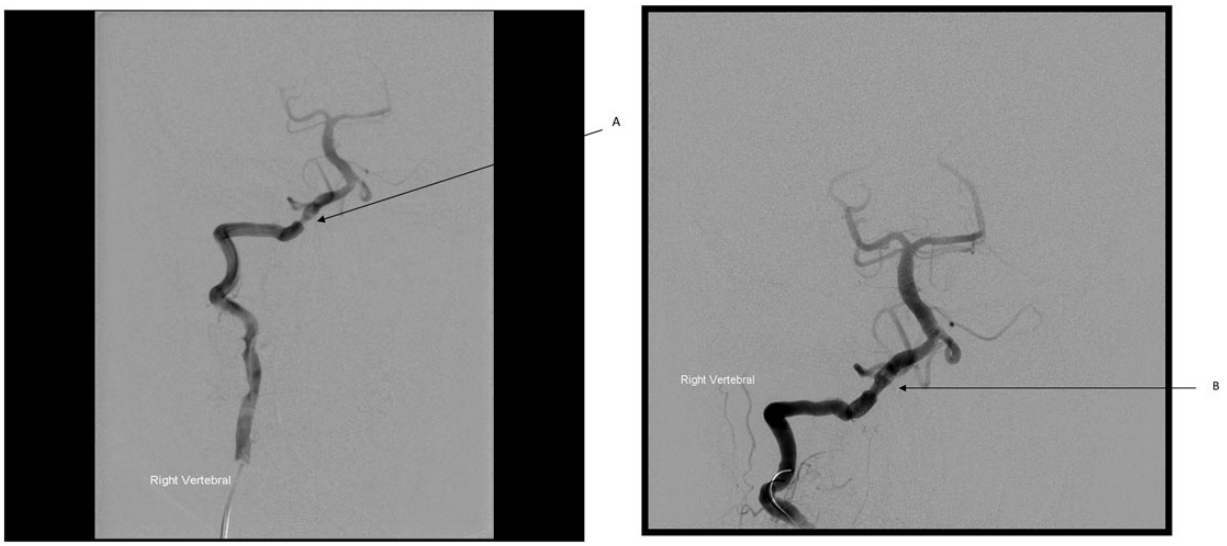

Fig 1 Vertebral artery pre-stenting: A, point of narrowing. Vertebral artery post-stenting: B, stent *in situ*.

patients. Oxygen saturation should be maintained at above 92%, with oxygen partial pressure of >8 kPa, and normocapnia. All patients should have continuous monitoring of heart rate, respiratory rate, ECG, and capnography. Arterial pressure should be measured invasively if obtainable quickly. Systolic arterial pressure should be maintained between 140 and 180 mm Hg with a diastolic arterial pressure of <105 mm Hg.[12] Patients who have undergone general anaesthesia should be extubated early, and have full neurological assessment. They should be monitored post-procedure in a high dependency unit.

The Pragmatic Ischaemic Stroke Thrombectomy Evaluation (PISTE) trial is a randomized controlled trial to evaluate whether additional mechanical thrombectomy device treatment improves functional outcome in patients with large artery occlusion who have received i.v. thrombolytic drug treatment as standard care. The trial consists of two arms: i.v. alteplase administered within 4.5 h of onset of stroke symptoms *vs* i.v. alteplase and additional mechanical thrombectomy procedure to commence within 90 min of the start of i.v. rtPA infusion. PISTE is scheduled to complete by August 2017.

Embolization of intracranial tumours

These procedures are performed before open surgery, to reduce tumour vascularity and facilitate surgical excision. There may be significant postoperative tumour swelling and a short preoperative course of steroid may be required. Severe post-procedural pain may occur if dural vessels are embolized.[8]

Carotid artery balloon test occlusion

This aims to test the adequacy of the cerebrovascular collateral circulation before electing to occlude the carotid artery, which may be necessary for surgery for tumours involving the skull base.[9] It is performed under local anaesthetic, with continuous neurological assessment and anaesthetic presence in the case of inadequate cerebrovascular collateral circulation leading to loss of consciousness. The use of deliberate hypotension can increase the sensitivity of the test. Owing to blood flow stasis distal to the point of balloon occlusion in the artery, optimal heparinization is essential to minimize the risk of clot formation.[13]

Sclerotherapy of venous angiomas

Craniofacial venous malformations are congenital disorders, which can be disfiguring and may impinge on the airway and affect swallowing. Under fluoroscopic guidance, 95% ethanol is injected percutaneously into the lesion, causing a chemical burn and shrinking the lesion.[9] Marked swelling can occur post-procedure, and the airway must be assessed before extubation.

Methods of imaging

Computerized tomography

The CT scanner is a ring-shaped structure, which can rotate and tilt. X-ray beams are emitted from one side of the centre opening and aimed directly across to a detector on the opposite side, which measures the amount of radiation absorbed by the body part in question. The CT table moves so that the X-ray beam follows a spiral path. High-quality images can be obtained rapidly.

Dyna-CT

Dyna-CT is an X-ray technique, which allows the acquisition of a 3D image with a fixed C-arm, where the C-arm rotates around the isocentre of the body part in question and a few hundred 2D images are obtained. A cone beam reconstruction is then performed.[8]

CT angiography

CTA combines traditional CT scanning with i.v. injection of contrast allowing visualization of blood vessels and qualitative assessment of flow. It does not give any assessment of the adequacy of flow. CTA is widely used in the diagnosis of vasospasm.

CT perfusion imaging

CT perfusion imaging is an important adjunct to CT and CTA. It allows for quantification of perfusion in the brain, and thus delineates areas of the brain which may be salvageable by intervention (clot retrieval or thrombolysis).

Magnetic resonance imaging

The patient lies within a powerful magnet, and high-quality images are obtained of the area in question. Hazards of general anaesthesia in the MRI suite include those of remote site anaesthesia, and also the anaesthetist being remote to the patient in a control room during scanning. MRI compatible monitoring must be used. Other considerations include the need for long extension tubing and infusion lines.

Magnetic resonance angiography

MRA combines MRI scanning with the i.v. injection of gadolinium to allow visualization of blood vessels and flow within them.

DSA and fluoroscopy

Initially, a pre-contrast (mask) picture is taken (essentially a plain X-ray). Fluoroscopy screening is then performed and all stable structures common to both images such as bone shadows and other non-vascular structures are subtracted digitally from the mask image. Simultaneous angiography is performed by injecting contrast into the circulation. As the contrast is not on the mask image, it is not subtracted, leaving an image of the vessel (the road map). To see the radio-opaque micro-catheter tip, the real-time image of the micro-catheter is superimposed onto the road map, allowing the radiologist to follow the micro-catheter tip through the vascular circulation. Subsequently, any items introduced onto the roadmap (e.g. stents or coils) are clearly visible.[3,8] Patient movement can cause image degradation and thus decrease the quality of images obtained. Roadmap fluoroscopic imaging has allowed interventional neuroradiologists to obtain angiographic images of a blood vessel or lesion by injecting only a small amount of contrast medium; and to maintain this angiographic image while superimposing live fluoroscopic (X-ray) images on the angiographic image. In essence, giving the interventional radiologist a 'roadmap' of the blood vessel and lesion, such as a cerebral aneurysm.

Anaesthetic considerations

Patients undergoing interventional neuroradiological procedures may be elective patients in whom incidental findings of aneurysm, AVM, or other intracranial pathology have been diagnosed. These interventional neuroradiological procedures are being undertaken as primary prevention techniques to avoid disease progression. Other cases may be more urgent, for example,

those with an SAH who may need cerebral angiography and endovascular treatment within 24–48 h. Other patients may present as emergency cases, having suffered sudden and catastrophic neurological injury as a result of a thromboembolic stroke. Many of the patients who have suffered neurological injury may be confused, in pain, have involuntary movements, or are un-cooperative. Interventional neuroradiology procedures can be technically challenging and long, and it may therefore be difficult, uncomfortable, and stressful for a patient to remain still on the angiography table. A motionless and at times, apnoeic patient is needed to minimize motion artifact, and to enable high-quality images to be obtained. With advancements in interventional neuroradiology techniques, general anaesthesia is increasingly being performed in the radiology suite.

General anaesthesia also allows the provision of a physiologically stable patient where arterial pressure, ventilation, and ICP can be controlled.

Challenges of general anaesthesia in the interventional neuroradiology suite include those of remote site anaesthesia, especially dim lighting and a lack of full range of equipment and help, otherwise available in main theatres.

Preoperative

Before operation, history of current illness, pathology, multisystem effects, and review of imaging should be undertaken. The patient should be examined for Glasgow coma score, pupil size and reactivity, and focal neurological deficits elicited and documented. The history of renal impairment and use of medications such as metformin should be ascertained. Renal function (urea and creatinine) should be tested before administration of contrast. Metformin is not recommended for use in diabetics with renal impairment because it is exclusively excreted by the kidneys, and accumulation of metformin can lead to lactic acidosis. Metformin should be withheld post-contrast if eGFR is <60 ml min^{-1}. Women of child-bearing age should have a negative pregnancy test or confirm that they are not pregnant, due to high dose of ionizing radiation exposure. All patients should have preoperative blood tests—full blood count, urea and electrolytes, coagulation screen, and a valid group and save sample in the case of bleeding. Allergy history to iodine, shellfish, or contrast should specifically be ascertained. In the emergency patient who is not starved, a rapid sequence induction should be performed, with techniques used to minimize the increases in ICP.

Induction

Cerebral protection strategies (arterial pressure targets systolic 100–160 mm Hg, avoidance of hypertension which increases the risk of re-bleeding, avoidance of hypotension to ensure adequate perfusion to ischaemic areas, normocapnia 4.5–5 kPa, and avoidance of hypoxia) should be used during induction to prevent secondary damage to the brain. Vasopressors may be required during induction and maintenance. A south facing RAE or reinforced tracheal tube is used to prevent kinking or displacement by the C-arm of the image intensifier.

Standard monitoring—ECG, non-invasive arterial pressure, and pulse oximetry—should be supplemented with invasive arterial monitoring to allow for arterial pressure monitoring and sampling for monitoring of anticoagulation.

I.V. access with large-bore cannulae should be secured, due to the potential for catastrophic bleeding.

Temperature control—procedures can be long, and angiography suites typically cold. Patients should be actively warmed to maintain normothermia.

Nasogastric (NG) tube insertion—some procedures require the administration of loading doses of aspirin 300 mg and clopidogrel 300 mg to be given intraoperatively, at the radiologists' request. An NG tube may be inserted before the procedure and position confirmed by on-table scanning at the start of the procedure. In some centres, an i.v. preparation of aspirin is available.

Owing to the large volumes of endovascular catheter flush and diuretic effect of contrast, a urinary catheter is essential.

Maintenance

Interventional neuroradiological procedures are rarely painful, but they do require a motionless patient and episodes of controlled apnoea. This can be achieved by total i.v. or inhalation anaesthetic in conjunction with intermittent boluses of neuromuscular blocking agent or infusion, or remifentanil infusion. Nitrous oxide should not be used as it may cause expansion of air emboli, which may be inadvertently introduced.

Specific considerations

Radiation protection

Patients and staff are exposed to high-dose ionizing radiation. Sources of radiation include direct radiation from X-ray tube, leakage through the collimators' protective shielding, and radiation that is scattered from the patient during imaging. Staff should minimize their exposure by wearing lead aprons of at least 0.5 mm thickness, thyroid shields, and maximize their distance from the source of ionizing radiation as the dose of radiation decreases proportionally from the source, according to the inverse square law (Table 2).

Contrast and flush

Up to 2 litres of flush, and up to 300 ml of contrast are used. All patients are at risk for the development of acute contrast-induced nephropathy. Limiting the dose of contrast and good hydration lessen the risk of precipitating acute kidney injury. Patients should have their renal function monitored for 72 h post-procedure.

Anticoagulation

The anaesthetist is often required to administer heparin i.v. to minimize thromboembolic complications and prevent vessel occlusion. A baseline activated clotting time (ACT) is obtained and then a dose of 70–100 units kg^{-1} of heparin is given, followed by measurement of the ACT, aiming for a target of 2–3 times baseline.

Patient positioning

The patient's head is usually at the opposite end to the anaesthetist and anaesthetic machine. This requires extensions to anaesthetic tubing and lines which must be secured. The angiography table also moves.

Table 2 Comparison of doses of ionizing radiation

Chest X-ray	0.02 mSv	1 CXR equivalent
Abdominal X-ray	0.06 mSv	3 CXR
CT scan of head	1.4–2 mSv	100 CXR
Cerebral angiogram	5 mSv	250 CXR
CT scan of chest	6.6 mSv	300 CXR
Interventional cerebral angiogram	7–10 mSv	300–500 CXR

Extubation

Smooth emergence is important to avoid coughing and thus increases in ICP, with possible re-bleeding and rupture of unprotected or partially protected aneurysms.

Postoperative care

The patient will often require transfer through the hospital to appropriate recovery facilities or high dependency unit for close haemodynamic and neurological monitoring in anticipation of potential complications.

The future

There have been many advances in endovascular stroke devices, with increased re-canalization rates and decreased procedural time. Results of the PISTE trial in 2017 will provide invaluable data on the management of hyperacute ischaemic stroke. In patients with atherosclerosis, drug-eluting stents such as sacrolimus and paclitaxel-eluting stents are now being used for symptomatic intracranial and vertebral artery stenosis. As advances continue to be made, increasingly more complex cases will be amenable to treatment in the interventional neuroradiology suite.

Declaration of interest

None declared.

MCQs

The associated MCQs (to support CME/CPD activity) can be accessed at https://access.oxfordjournals.org by subscribers to *BJA Education*.

References

1. NCEPOD Managing the Flow? A review of the care received by patients who were diagnosed with an aneurysmal subarachnoid haemorrhage, 2013
2. Dirringer M. Management of aneurysmal subarachnoid haemorrhage. *Crit Care Med* 2009; **37**: 432–40
3. Appleby I, Gregory T. Anaesthesia for interventional neuroradiology. *Anaesth Intensive Care* 2010; **11**: 366–8
4. Varma MK, Price K, Jayakrishnan V, Manickam B, Kessell G. Anaesthetic considerations for interventional neuroradiology. *Br J Anaesth* 2007; **99**: 75–8
5. Luoma A, Reddy U. Acute management of aneurysmal subarachnoid haemorrhage. *Contin Educ Anaesth Crit Care Pain* 2013; **13**: 52–8
6. Schulenburg E, Matta B. Anaesthesia for interventional neuroradiology. *Curr Opin Anaesthesiol* 2011; **24**: 426–32
7. Molyneux AJ, Kerr RSC, Birks J *et al*. for the ISAT collaborators. Risk of recurrent subarachnoid haemorrhage death or dependence, and standardised mortality ratios after clipping or coiling of an intracranial aneurysm in the International Subarachnoid Aneurysm Trial: longterm follow up. *Lancet Neurol* 2009; **8**: 427–33
8. Patel S, Appleby I. Anaesthesia for interventional neuroradiology. *Anaesth Intensive Care* 2013; **14**: 387–90
9. Hashimoto T, Gupta DK, Young WL. Interventional neuroradiology—anesthetic considerations. *Anesthesiol Clin North Am* 2002; **20**: 347–59
10. Reddy U, Smith M. Anesthetic management of endovascular procedures for cerebrovascular atherosclerosis. *Curr Opin Anaesthesiol* 2012; **25**: 486–92
11. Lee CZ, Young WL. Anesthesia for endovascular neurosurgery and interventional neuroradiology. *Anesthesiol Clin* 2012; **30**: 127–47
12. Society of Neuroscience in Anesthesiology and Critical Care Expert Consensus statement: anesthetic management of endovascular treatment of acute ischemic stroke, 2014
13. Sturgess J, Matta B. Anaesthesia for intracranial vascular surgery and carotid disease. In: Matta B, Menon DK, Smith M, eds. *Core Topics in Neuroanaesthesia and Neurointensive Care*. Cambridge: Cambridge University Press, 2011; 178–96