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Anaesthesia for elective neurosurgery

J. Dinsmore*

Department of Anaesthesia, St George's Hospital, London SW17 0RE, UK
**E-mail: judith.dinsmore@stgeorges.nhs.uk*

Neuroanaesthesia continues to develop and expand. It is a speciality where the knowledge and expertise of the anaesthetist can directly influence patient outcome. Evolution of neurosurgical practice is accompanied by new challenges for the anaesthetist. Increasingly, we must think not only as an anaesthetist but also as a neurosurgeon and neurologist. With the focus on functional and minimally invasive procedures, there is an increased emphasis on the provision of optimal operative conditions, preservation of neurocognitive function, minimizing interference with electrophysiological monitoring, and a rapid, high-quality recovery. Small craniotomies, intraoperative imaging, stereotactic interventions, and endoscopic procedures increase surgical precision and minimize trauma to normal tissues. The result should be quicker recovery, minimal perioperative morbidity, and reduced hospital stay. One of the peculiarities of neuroanaesthesia has always been that as much importance is attached to wakening the patient as sending them to sleep. With the increasing popularity of awake craniotomies, there is even more emphasis on this skill. However, despite high-quality anaesthetic research and advances in drugs and monitoring modalities, many controversies remain regarding best clinical practice. This review will discuss some of the current controversies in elective neurosurgical practice, future perspectives, and the place of awake craniotomies in the armamentarium of the neuroanaesthetist.

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Neuroanaesthesia continues to develop and expand. It is a speciality where the knowledge and expertise of the anaesthetist may directly influence patient outcome. Evolution of neurosurgical practice is accompanied by new challenges for the anaesthetist with greater focus on functional and minimally invasive procedures. The emphasis remains on the provision of good operative conditions, assessment and preservation of neurological function, and a rapid, high-quality recovery.

Basic principles

The basic principles of neuroanaesthesia remain unchanged—the provision of optimal operative conditions, maintenance of cerebral perfusion pressure (CPP), and cerebral oxygenation. However, despite advances in drugs and monitoring modalities, neuroanaesthesia is steeped in tradition and many controversies remain regarding best clinical practice.

Drugs

Despite theoretical benefits of i.v. agents, volatile agents remain popular. Numerous studies have described their differential effects on cerebral haemodynamics and intracranial pressure (ICP). In a study comparing desflurane, isoflurane, and sevoflurane in a porcine model of intracranial hypertension, at equipotent doses and normocapnia, cerebral blood flow (CBF) and ICP were greatest with desflurane and least with sevoflurane.[26] The authors went on to confirm these findings in clinical studies, demonstrating that sevoflurane caused the least vasodilatation.[27] In two different studies in healthy patients, isoflurane was found to impair autoregulation, although this was reversible with hyperventilation, while autoregulation was virtually intact with sevoflurane 1–1.2% at normocapnia.[44 52] Although further large-scale studies are needed, sevoflurane appears to be the most suitable volatile agent for neuroanaesthesia.

Propofol has many theoretical advantages by reducing cerebral blood volume (CBV) and ICP and preserving both autoregulation and vascular reactivity. In healthy subjects, propofol reduced CBF, as measured by positron emission tomography (PET), more than sevoflurane at equipotent concentrations.[41] The effects of desflurane, isoflurane at 1 MAC and propofol on the CBF velocity, were investigated in children presenting for general surgery.

When propofol was changed to desflurane the middle cerebral artery flow velocity increased, but when desflurane was changed to isoflurane there was no further change.[56] Neurosurgical patients anaesthetized with propofol were found to have lower ICP and higher CPP than those anaesthetized with isoflurane or sevoflurane.[49]

However, once again, it has not always been possible to demonstrate these benefits consistently or clinically. In healthy subjects, the estimated CPP decreased under propofol but not sevoflurane anaesthesia at moderate hypotension[43] and, with hypocapnia, it decreased with sevoflurane group but not propofol. However, these results apply only to patients with normal ICP. The reduction in CBF seen with propofol has been associated with a decrease in jugular venous oxygen saturation, particularly during hypocapnia, something not seen with sevoflurane.[32] However, more recent data suggest that increases in propofol concentrations do not affect jugular venous bulb oxygen saturations within the dose range used clinically.[29]

The detrimental effects of nitrous oxide are well documented.[22] In healthy subjects, inhalation of nitrous oxide 50% causes a significant increase in estimated CPP and a decrease in zero flow pressure.[21] In patients with decreased intracranial compliance any increase in CBV and ICP would be detrimental. Again in healthy subjects, the addition of nitrous oxide to propofol or sevoflurane anaesthesia does not alter regional CBF as measured by PET, but does attenuate reductions in CBF and cerebral metabolic rate for oxygen produced by the agents alone. Sevoflurane also reduces the oxygen extraction fraction at a moderate depth of anaesthesia.[31] However, none of this can be extrapolated directly into clinical practice where other agents influence the effects of nitrous oxide. Nitrous oxide has been used for countless anaesthetics and, in practical terms, it is difficult to demonstrate adverse clinical outcome.

Interestingly, in a study of almost 700 patients, the drugs used for induction or maintenance of anaesthesia were not independent risk factors for intraoperative brain swelling. Risk factors included: ICP at the start of surgery, the degree of mid-line shift on computed tomography (CT) scan, and histological diagnosis of glioblastoma or metastasis.[50]

Steroids

Dexamethasone is prescribed routinely to reduce cerebral oedema, but even a single 10 mg dose can significantly increase blood glucose concentrations in non-diabetic patients.[48] There is evidence to support tight glycaemic control in critically ill, neurologically impaired patients,[34] but whether it improves outcome in elective neurosurgical patients is yet to be established. Nevertheless adverse metabolic and cerebral ischaemic effects of high-blood glucose concentrations are well documented.[18]

Positioning

Optimal patient positioning can reduce ICP and brain swelling. In patients undergoing craniotomy for cerebral aneurysm, a 10° reverse Trendelenburg tilt decreased ICP, although the CPP was unchanged.[59] In children with space-occupying lesions, brain swelling was more pronounced and the ICP higher in the prone position when compared with the supine.[57]

Despite the well-recognized complications of the sitting position, several case series have established its relative safety in carefully selected patients.[24 36] A magnetic resonance imaging (MRI) study in healthy volunteers supports the clinical findings of an improvement in cerebrovascular and intracranial compliance from the supine to the sitting position because of reduced intracranial blood and cerebrospinal fluid volume.[1]

Monitoring

Neurological monitoring aims to detect changes in cerebral haemodynamics, oxygenation, and neuronal function. Many new monitoring tools are not yet fully accepted as standard care. Intraoperative electrophysiological monitoring may help to prevent postoperative deficits. In a study of 658 intracranial and spinal procedures, it was found to have a sensitivity of 79% and a negative predictive value of 96% for detection of neurological injury.[62] Both i.v. and volatile agents affect evoked potential characteristics but propofol causes significantly less suppression at a comparable depth of anaesthesia.[38] Electrophysiological monitoring is also used to assess the depth of anaesthesia. Bispectral index and spectral entropy have been used with variable success in neuroanaesthesia.[16 23 47]

Recovery

A speedy recovery allows prompt neurological assessment and early detection of complications that require immediate intervention. New shorter acting agents have made a rapid recovery easier to achieve, although studies have failed to demonstrate consistent differences between volatile agents and total i.v. anaesthesia (TIVA). One study comparing sevoflurane and fentanyl with propofol and remifentanil found no differences in emergence time, early postoperative cognitive function, pain, nausea, or vomiting but did identify more episodes of intraoperative hypotension and hypertension in the TIVA group.[40] In contrast, when sevoflurane and remifentanil were compared with propofol and remifentanil, although there were no differences in operative conditions, pain, nausea, or vomiting, there was more hypotension in the sevoflurane group.[58]

When comparing the effects of alfentanil, fentanyl, and remifentanil on haemodynamic and respiratory variables in patients undergoing craniotomy for tumour, there were no significant differences except a reduced time to eye opening in the remifentanil group.[12] In a separate study,

propofol with remifentanil rather than sufentanil was associated with an earlier return of cognitive function.[9]

Systemic hypertension is common during emergence and may contribute to the development of postoperative haematomas.[6] Various strategies have been used in an attempt to attenuate this response.[10] The increased use of remifentanil may be associated with more postoperative hypertension,[20] but this might be avoided with effective transitional analgesia.[5] The α-2 agonist dexmedetomidine has been shown to provide good haemodynamic stability during intracranial tumour surgery, attenuating the response to intubation and emergence.[60]

Pain, nausea, and vomiting

There have been several reviews of postoperative pain in neurosurgical patients, but no large-scale studies determining effective treatments and side-effects. Codeine-based analgesia is often inadequate, as is acetaminophen alone and non-steroidal anti-inflammatory drugs remain controversial.[17] Morphine, although safe and effective in reducing pain scores, is associated with an increased incidence of nausea, vomiting, and urinary retention. Multimodal analgesia regimes seem to be more successful, as much for their ability to reduce opioid side effects, as provision of effective pain control.[37] Scalp infiltration using bupivacaine 0.375% with epinephrine 1:200 000, or ropivacaine 0.75% decrease postoperative pain scores and morphine consumption, but only for the first 2 h after surgery.[35]

Nausea and vomiting are common after craniotomy despite the widespread use of dexamethasone. Women and any patients undergoing infratentorial surgery are particularly at risk. Unfortunately there is no convincing evidence in favour of one antiemetic agent over another and, particularly in high-risk patients, it may be necessary to administer a combination of antiemetics. Ondansetron, droperidol, and dexamethasone can each reduce the risk of nausea and vomiting by 25%[2] and metoclopramide and scopolamine have also been used with some success.[37] In non-neurosurgical patients, TIVA with propofol and the use of air rather than nitrous oxide have been shown to be effective.[2]

Future perspectives

Few could have imagined the tremendous growth of endovascular surgery over the last 30 yr. With further advances in imaging, computing, and optics the use of minimally invasive and functional procedures will continue to increase. Image-guided navigation (neuronavigation) systems have dramatically improved the ability to treat seemingly inaccessible intracranial lesions. One of the present limitations of neuronavigation is the use of preoperative images intraoperatively, at a time when anatomy is dynamically changing. As technology improves the use of real-time imaging such as intraoperative MRI will increase. Endoscopic surgery is now routine for intraventricular pathology but advances in optics and scope design are likely to extend its role into all types of intracranial surgery.

The advantages of minimally invasive surgery include: reduced trauma to normal tissue, preservation of function, more rapid recovery, reduced morbidity, and shorter hospital stay. Some procedures can be performed under minimal or local anaesthesia. However, anaesthetists may be faced with providing care for a newly developed procedure of which there is limited experience. A comprehensive preoperative assessment and management plan is essential. Awareness of potential complications and vigilance enables early identification of airway compromise, seizures, and changes in neurological status.

Awake craniotomy

Awake craniotomy is gaining popularity worldwide. Routine for epilepsy surgery for many years, it is now increasingly used for the removal of intracranial lesions in or adjacent to eloquent brain. Despite the risks in such cases, maximal tumour resection seems to be an important determinant in prognosis, increasing median survival time and time to recurrence.[45] Cortical mapping allows the planning of safe resection margins and, with continuous neurological assessment, maximal resection with minimal postoperative neurological dysfunction can be achieved. This enables patients previously deemed inoperable to benefit from surgery. In addition, functional stereotactic neurosurgery is increasingly being used in the surgical treatment of intractable movement disorders such as Parkinson's disease and dystonias. The enthusiasm for awake craniotomy is such that it has even been suggested that it could become routine for supratentorial tumours irrespective of functional cortex. In a prospective trial of 200 patients, the procedure was well tolerated with reduced intensive care time and hospital stay.[61]

Techniques

Anaesthetic techniques for awake craniotomy have evolved along with the surgical indications, but significant challenges remain. The anaesthetist must provide adequate analgesia and sedation, haemodynamic stability, and a safe airway but also an alert, cooperative patient for neurological assessment. Numerous techniques have been described from local anaesthesia to conscious sedation to general anaesthesia using an asleep–awake–asleep (AAA) technique, with or without airway instrumentation. With no consensus as to the optimal regimen most institutions have developed their own techniques to suit the needs of their surgeons and individual preferences.

Whatever technique is used adequate local anaesthesia is essential. Scalp infiltration with large volumes of local anaesthetic or scalp blocks carries the potential risk of

local anaesthetic toxicity in patients who are already prone to seizures. Several studies have measured plasma concentrations of local anaesthetics and demonstrated that absorption is rapid and that potentially toxic plasma concentrations were achieved in some patients.[4 14 15] However, the clinical signs or symptoms suggestive of toxicity were not evident in previous studies.

Today propofol is the most frequently used drug for both sedation and general anaesthesia. It provides titratable sedation and a rapid smooth recovery, decreases the incidence of seizures and, when stopped for awakening, minimizes interference with electrocorticographic recordings. It is often used as a target-controlled infusion and may be combined with remifentanil when changes in infusion rates of both drugs correlate well with effect site concentrations.[23 30] In a recent study of 50 patients comparing propofol and remifentanil with propofol and fentanyl for conscious sedation, there was no difference in conditions among groups and most patients were completely satisfied.[42] A retrospective analysis of an AAA technique using propofol and remifentanil showed that adequate conditions were obtained in 98% of patients with a median wake-up time of 9 min.[33]

Dexmedetomidine provides sedation and analgesia without respiratory depression and has been used as a sole agent, an adjunct, and a rescue drug for awake craniotomy.[39 46 51] It was used successfully for awake craniotomy in 10 consecutive patients. Five patients were sedated with midazolam, fentanyl, or remifentanil and five had an AAA technique using sevoflurane, spontaneous ventilation, and laryngeal mask airway (LMA). All received dexmedetomidine infusions $0.01-1.0\ \mu g\ kg^{-1}\ h^{-1}$ as an adjunct.[39] However, when used for sedation during embolization of cerebral arteriovenous malformations, dexmedetomidine $0.2-0.7\ \mu g\ kg^{-1}\ h^{-1}$ significantly impaired cognitive testing.[11] These patients had also received fentanyl and midazolam, and significant sedative synergism has been reported between midazolam and dexmedetomidine.[53] Dexmedetomidine $0.3-0.6\ \mu g\ kg^{-1}\ h^{-1}$ was used successfully as a sole agent during implantation of deep brain stimulators. It provided satisfactory sedation, did not mask clinical signs of Parkinson's disease and reduced the need for antihypertensives.[51]

Airway management is generally uneventful during sedation. However, any sedation inevitably runs the risk of hypoventilation or airway obstruction and there must always be a plan for securing the airway if necessary. In addition, patient positioning may limit access and further contribute to airway compromise. Various airway adjuncts have been described for awake craniotomy from a simple nasopharyngeal airway to a modified tracheal tube allowing topical delivery of local anaesthesia and reintubation over a fibre optic scope.[28] The LMA is a popular adjunct. It is well tolerated at lighter planes of anaesthesia particularly in conjunction with propofol and remifentanil, easy to insert and remove and it enables ventilation to be controlled, providing optimal operative conditions.[54] A cuffed oropharyngeal airway was used in 20 patients for an AAA technique with spontaneous ventilation.[3] Airway manipulation was required in one-third of patients in the supine position, but in none in the lateral position, and the authors suggested that airway manipulation is a safe alternative to the LMA. The use of non-invasive positive pressure ventilation (biphasic positive airway pressure and proportional assist ventilation) was described in two patients,[63] but there are obvious limitations to this technique. The nasal mask may be difficult to position, interfere with the surgical field, and patients may find it unpleasant. The successful use of pressure support ventilation has also been described for a patient with obstructive sleep apnoea.[19]

Intraoperative cortical testing

There is considerable inter-patient variability in the anatomical location and cortical representation of speech areas. Intraoperative mapping of speech involves the identification of Broca's area by producing speech arrest, and other cortical speech areas by a series of naming and word/sentence comprehension tests using books or slides. Recently, a computer program not only generating images on a small screen but also relaying images to the surgeon has been described.[13] This can include touch screen technology to allow dysphasic patients to respond to images. In patients who are fluent in more than one language, localization of speech may be problematic as there may be multiple cortical representation sites. Studies recommend performing multiple language mapping for all languages.[7]

Complications

The complications of awake craniotomy are summarized in Table 1. Although many studies have looked at complication rates (Table 2), it is difficult to tell which technique is associated with least complications. Most are retrospective, and even within individual series there may be involvement of multiple teams and different management protocols, making direct comparisons impossible.

When neurolept analgesia was compared with patient-controlled sedation using propofol for epilepsy surgery, the propofol group had fewer seizures but a higher incidence of transient respiratory depression.[25] Several studies have looked at complication rates with propofol and remifentanil. When comparing propofol and remifentanil sedation with propofol and fentanyl, there was no significant difference in complication rate among groups but an overall incidence of respiratory complications of 18%.[42] Four patients received mannitol electively and one at the surgeon's request for brain swelling. All adverse events were easily treated. Others using propofol and remifentanil for sedation noted frequent respiratory complications although these significantly decreased as they became more familiar with their protocol.[8] There have been several reviews of

Table 1 Complications of awake craniotomy

Respiratory
Airway obstruction
Respiratory depression
Cardiovascular
Hypotension
Hypertension
Neurological
Seizures
New neurological deficit
Brain swelling
Excessive sedation or uncooperative patient
Pain
Nausea and vomiting
Air embolism
Local anaesthetic toxicity
Pulmonary aspiration
Conversion to general anaesthesia

AAA techniques using propofol and remifentanil. In one, where no airway support other than nasal trumpets was used, there were frequent brief periods of apnoea and transient increases in arterial pressure. All of these patients received furosemide and mannitol on induction and there was no incidence of brain swelling.[33] Another study compared three patient groups—Group 1 sedated with propofol and fentanyl, Group 2 had an AAA technique with propofol, fentanyl, and spontaneous ventilation using a LMA, and Group 3 an AAA with propofol, remifentanil, and assisted ventilation using an LMA.[54] Airway obstruction developed in three patients in Group 1 (E'_{CO_2} was not recorded) and all patients in Group 2 had an E'_{CO_2} >6 kPa, at some point. However, there were no respiratory complications in Group 3, although these were small patient numbers.

Is awake craniotomy associated with more complications than general anaesthesia? One group reviewed the complication rate in 322 awake craniotomies for epilepsy surgery and compared these complications with 129 patients who had standard general anaesthesia for epilepsy surgery.[55] They used a standard AAA technique with propofol as a sole agent; spontaneous ventilation and no airway instrumentation. There were no reports of local anaesthetic toxicity, pulmonary aspiration, air embolism or death and no difference in the incidence of nausea, vomiting, or seizures among groups. However, respiratory complications such as arterial desaturation and significantly higher levels of Pa_{CO_2}, and haemodynamic complications such as hypotension, hypertension, and tachycardia were more common in the AAA group. Airway compromise occurred in only six patients (1.8%) and all of these were obese. Despite the higher Pa_{CO_2} in the AAA group, brain swelling was only noted in two patients but it was felt that this may have contributed to significant haemorrhage in one of these patients. With large numbers and a standard anaesthetic, this complication rate should give reassurance and be representative but only of this technique. All these patients were having epilepsy surgery and opioids were not used.

In summary, awake craniotomy is safe and well tolerated. The lack of consensus regarding the best technique is unsurprising considering the different surgical indications, intraoperative requirements, and patient groups involved. Careful patient selection, attention to detail, and good communication are vital in keeping complication rates low.

Conclusion

Although one of the oldest subspecialties of surgery, modern neurosurgery is where some of the greatest changes are happening and neuroanaesthesia practice must keep pace. Although the basic principles remain the same, new challenges are faced as indications for functional and minimally invasive neurosurgery increase. Anaesthesia provision for these new procedures may be very different, require new management strategies, and pose new risks. We may never reach a consensus on the ideal drug or the

Table 2 Comparison of incidence of complications in published reviews (expressed as percentages). *No comment can be made on the incidence of these complications as data either not collected or expressed as incidences. †Prospective trial, *n*=37; two groups: propofol *vs* neurolept sedation, no airway. ‡Prospective trial, *n*=50; two groups: propofol, fentanyl *vs* propofol, remifentanil, no airway. $Retrospective review *n*=19; propofol, remifentanil, assisted ventilation with LMA. #Retrospective review *n*=98; propofol, remifentanil, no airway. §Retrospective review *n*=332; propofol, no airway

Complications	Sedation		AAA		
	Herrick and colleagues[25] †	Manninen and colleagues[42] ‡	Sarang and Dinsmore[54] $	Keifer and colleagues[33] #	Skucas and Artru[55] §
Respiratory	5/0	24/12	0	Apnoea common	33
Haemodynamic					
Hypertension	*	4/0	20	N/A	11
Hypotension	*	0/8	0		56
Neurological					
Seizures	0/41	0/16	0	3	3
Tight brain	*	4/4	0	*	1
New deficits	*	0/4	5	*	*
Others					
Uncooperative	*	16/8	5	7	2
Pain	*	8/4	0	16	*
Nausea/vomiting	10/18	0/0	0	8	1

perfect recipe for neuroanaesthesia and continue to choose drugs and techniques which accommodate specific surgical requirements and personal preferences. However, further large-scale studies would greatly assist in this decision-making process.

Financial pressures to admit on the day of surgery, minimally invasive surgery and developments in neuroanaesthesia make the prospect of day-case neurosurgery a reality. However, as technological advances and new anaesthetic techniques push the boundaries of what or who is treatable, more than ever, close cooperation among the neurosurgeon, anaesthetist, and patient is vital.

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