British Journal of Anaesthesia **90 (2)**: 161–5 (2003)
DOI: 10.1093/bja/aeg037

BJA

Anaesthesia for awake craniotomy—evolution of a technique that facilitates awake neurological testing

A. Sarang[1] and J. Dinsmore*

Department of Anaesthesia, Atkinson Morley's Hospital, Copse Hill, Wimbledon, London SW20 0NE, UK

[1]Present address: Department of Anaesthesia, St Mary's Hospital, Praed Street, London, UK

**Corresponding author. E-mail: judith.dinsmore@btinternet.com*

Background. There is an increasing trend towards performing craniotomy awake. The challenge for the anaesthetist is to provide adequate analgesia and sedation, haemodynamic stability, and a safe airway, with an awake, cooperative patient for neurological testing.

Methods. The records of all patients who had awake craniotomy at our institution were reviewed. Patients were divided into three groups according to anaesthetic technique. Patients in Group 1 were sedated throughout the procedure. Patients in Groups 2 and 3 had an asleep–awake–asleep technique. Those in Group 2 were anaesthetized with a propofol infusion and fentanyl, and breathed spontaneously through a laryngeal mask airway (LMA†). Patients in Group 3 had total i.v. anaesthesia with propofol and remifentanil, and ventilation was controlled using an LMA. We noted the incidence of complications in each group.

Results. There were 99 procedures carried out between 1989 and 2002. Group 3 had the fewest complications. No patients in Group 3 developed hypercapnia (E'_{CO_2} >6 kPa), compared with all of the patients in Group 2. Patients in Group 1 had no E'_{CO_2} monitoring, but 7% developed airway obstruction. No patients in Group 3 required additional analgesia for pain, compared with 70% of patients in Group 2.

Conclusions. We have developed a technique for craniotomy, which facilitates awake neurological testing, is safe, and has good patient satisfaction.

Br J Anaesth 2003; **90**: 161–5

Keywords: anaesthetic techniques; complications; surgery, craniotomy

Accepted for publication: October 2, 2002

Awake craniotomy for epilepsy surgery has been routine for many years.[1] It is now also used for the resection of tumours located in the eloquent cortex. This includes the motor strip and Broca's speech area (dominant hemisphere), both in the frontal lobe, and Wernicke's speech area (dominant hemisphere) in the temporal lobe. Intraoperative neurological testing allows optimal tumour resection with minimal postoperative neurological dysfunction. Varying anaesthetic techniques for awake craniotomy have been described in the literature.[2–7] However, the majority of these have been adapted from those used for epilepsy surgery and concerns have been raised about patient cooperation, safety and acceptability. The challenge for the anaesthetist is to find a technique which provides adequate sedation, analgesia, and respiratory and haemodynamic control, but also an awake and cooperative patient for neurological testing.

One neurosurgeon at our institution regularly performs awake craniotomies for tumours near functional areas of the brain. This has given us the opportunity to develop a technique which fulfils these requirements, provides good operative conditions, and is acceptable to the patient. We reviewed all patients who had awake craniotomy, and describe the evolution of this technique, the incidence of complications, and the quality of the awake period.

Methods

We reviewed the anaesthetic management, incidence of complications, and discharge time of all patients who had undergone awake craniotomy for tumour surgery since

†LMA® is the property of Intavent Limited.

1989. Approval was granted by the chairman of the local ethics committee for a confidential review of patient notes. Patients were identified from the neurosurgical database and operating department records. These notes were retrieved and the medical records reviewed. Nineteen patients were assessed prospectively. The year of operation and physical characteristics, including patient age, sex, weight and histological diagnosis, were recorded. The anaesthetic records, operation notes, and the postoperative notes were examined, and the incidence of complications and the time to hospital discharge were recorded.

Complications were classified as *anaesthetic*: inadequate or excessive sedation, pain, nausea or vomiting; *respiratory*: oxygen saturation <90%, increase in E'_{CO_2} (>6 kPa), hypoventilation (<8 bpm), or airway obstruction; *haemodynamic*: systolic blood pressure <80 or >170 mm Hg, or heart rate <40 or >110 beats min^{-1}; or *neurological*: convulsions, brain swelling or development of a new neurological deficit.

Patients were placed into one of three groups depending on the anaesthetic technique used (Table 1). The majority of cases were anaesthetized by one of four anaesthetists, and the anaesthetic technique was modified over the years from providing a type of conscious sedation to a true asleep–-awake–asleep technique. There were never any anaesthetic protocols, but it became obvious on reviewing the patient records that there were three main anaesthetic techniques. All patients received dexamethasone i.v. and anticonvulsants for seizure prophylaxis during the preoperative period. They were not premedicated and monitoring consisted of electrocardiogram (ECG), Sp_{O_2}, E'_{CO_2}, and invasive arterial pressure. The operative site was infiltrated with a mixture of bupivacaine 0.25% and lidocaine 0.5% in Groups 1 and 2, and with bupivacaine 0.5% in Group 3.

Group 1

Patients in Group 1 received fentanyl, and either droperidol or midazolam, followed by a propofol infusion. Patient's age, weight and response to the surgical stimulus dictated drug dosage. Cocaine paste was applied to both nostrils; a nasopharyngeal airway was inserted; and the craniotomy proceeded with the patient breathing spontaneously. Varying degrees of airway obstruction were often encountered, head position being dictated by the need for surgical access. Limited repositioning was sometimes possible, but jaw thrust or manual airway support was often necessary. The fear of respiratory depression limited the use of fentanyl. When the tumour was located, the dose of propofol was reduced and the patient allowed to waken until they were able to comply with simple testing. The nasopharyngeal airway was often left in position during this period. When tumour resection was complete, the dose of propofol was increased for closure.

Group 2

This technique was modified in 1996 by the use of the laryngeal mask airway (LMA†). This allowed better control of the airway, a means of assessing adequacy of respiration via the E'_{CO_2} trace, and the ability to control ventilation if the need arose. When the tumour was located, the propofol was stopped, the LMA was removed, and the patient was allowed to wake up. For closure of the surgical incision, the propofol infusion was restarted and the LMA reinserted. These patients received fentanyl, but not droperidol or midazolam.

Group 3

Our present technique is a true asleep–awake–asleep technique. Additional monitoring is provided by using bispectral index score (BIS). Patients receive total i.v. anaesthesia with a target-controlled infusion of propofol and a remifentanil infusion. An LMA is inserted and ventilation controlled until the tumour is exposed. The rates of propofol and remifentanil are adjusted in response to changes in the haemodynamic variables, the response to surgical stimulation, and the BIS. The remifentanil infusion and artificial ventilation allow control of P_{CO_2} based on arterial blood gases, providing good operative conditions. All patients receive acetaminophen 1 g p.r., diclofenac 75 mg i.v., unless contraindicated, and ondansetron 4 mg i.v.

When the tumour is exposed, the remifentanil is reduced until spontaneous respiration resumes. The LMA is then removed. The propofol infusion is stopped and the patient allowed to waken (Fig. 1). A background infusion of remifentanil of 0.005–0.01 μg kg^{-1} min^{-1} is used to provide additional analgesia during the awake period. When tumour resection is complete, the patient is re-anaesthetized and the LMA replaced. Ventilation is again controlled until com-

Table 1 Anaesthetic technique used in each group

Group 1	Group 2	Group 3
Propofol infusion Droperidol ± midazolam	Propofol infusion	Propofol infusion (target-controlled)
Fentanyl up to 100 μg	Fentanyl up to 100 μg	Remifentanil infusion: 0.05–2 μg kg^{-1} min^{-1} when asleep; 0.005–0.01 μg kg^{-1} min^{-1} when awake
Nasal airway	LMA	LMA
Spontaneous ventilation	Spontaneous ventilation	Controlled ventilation

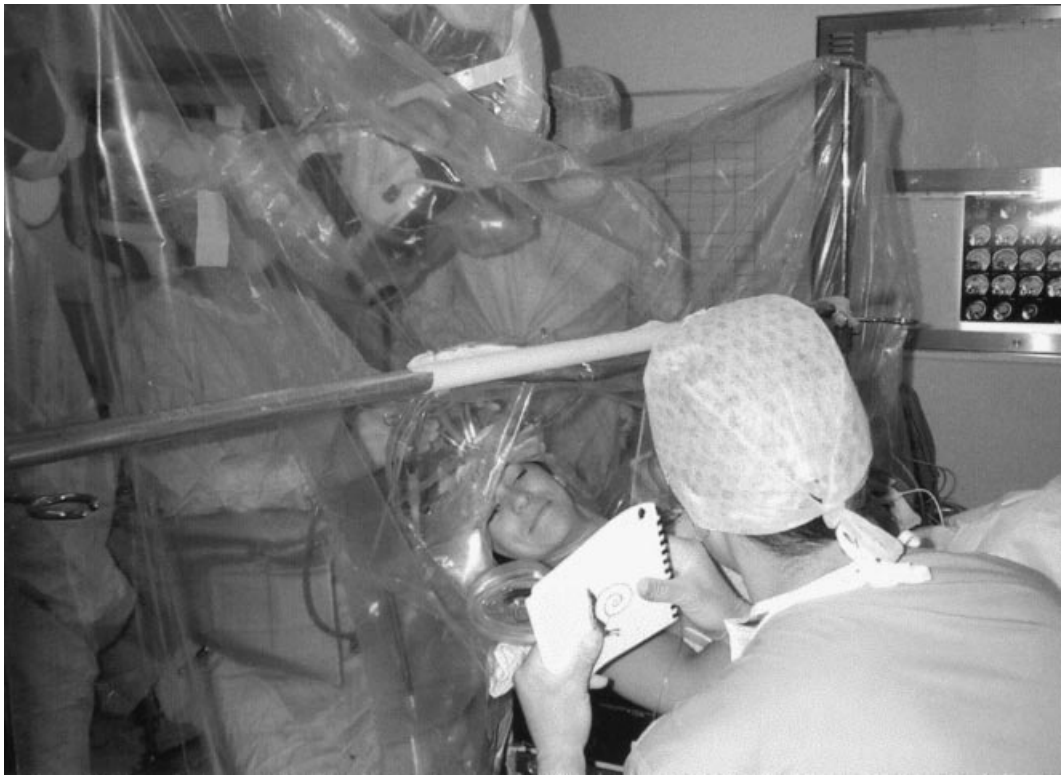

Fig 1 A patient undergoing neurological assessment during an awake craniotomy.

Table 2 Incidence of complications seen in each group. *Information unavailable

Complications	Number of patients (%)		
	Group 1	Group 2	Group 3
Pain	*	24 (70)	0
Excess sedation/uncooperative	0	1 (3)	1 (5)
Airway obstruction	3 (7)	0	0
Hypercapnia	*	34 (100)	0
Hypotension	0	2 (6)	4 (21)
Hypertension	0	4 (11)	0
Convulsions	0	2 (6)	0
Neurological deficit	*	3 (8)	1 (5)

pletion of surgery. Patients are given morphine up to 10 mg for postoperative analgesia before returning to the recovery room.

Results

Ninety-nine procedures between 1989 and June 2002 were reviewed. The patient population consisted of 82 individuals, as 17 of the procedures were re-operations. The majority of procedures have been since 1995. The ages of the patients ranged from 14 to 66 years, with a median age of 36 years. The median body weight was 74 kg, with a range of 54–104 kg. There were 57 males and 42 females. The mean duration of anaesthesia and surgery was 3 h, and the time awake averaged 75 min. There were 46 patients in Group 1, 34 patients in Group 2 and 19 patients in Group 3.

The anaesthetic records were missing from the patient notes in five cases, and it was difficult to obtain accurate information on the incidence of anaesthetic complications in some of the earlier patients. The patients in Group 1 remained sedated throughout the awake period, but there were no documented problems with pain, excessive sedation, or of lack of patient cooperation. Twenty-four patients in Group 2 received supplementary fentanyl during the awake period for discomfort during tumour resection. One patient in Group 2 was restless and uncooperative and had to be re-anaesthetized. No patients in Group 3 complained of pain (Table 2). One procedure in Group 3 had to be

abandoned because of excessive sedation, but this same patient underwent repeat awake craniotomy the following week, without complications. Nausea or vomiting was not reported in any group.

The patients in Group 1 had no E'_{CO_2} monitoring. Three patients in this group had documented airway obstruction (Table 2). However, there was no recorded desaturation or hypoventilation. All patients in Group 2 had an E'_{CO_2} >6 kPa at some stage during their procedure. There were no airway problems in Group 3.

There were no haemodynamic complications in Group 1, but this was based on limited anaesthetic notes. Two patients in Group 2 and four patients in Group 3 had transient hypotension after induction of anaesthesia or on local anaesthetic infiltration. Four patients in Group 2 had episodes of hypertension during closure of the craniotomy, requiring treatment with labetalol. Two patients in Group 2 developed intraoperative seizures (Table 2). In one patient, this resulted in a prolonged post-ictal period and the procedure was abandoned. Three patients in Group 2 and one patient in Group 3 developed mild neurological deficits.

Discussion

Although awake craniotomy for epilepsy surgery is well established, awake craniotomy for tumour surgery has become popular more recently. There are many theoretical advantages of radical tumour resection. These include an increased chance of an accurate pathological diagnosis; reduced tumour bulk before adjuvant therapy; reduction in intracranial pressure; and the decreased probability of dedifferentiation of a low grade tumour.[8] Retrospective data suggest that median survival time and time to recurrence are improved. However, resection may be limited by tumour location and the theoretical benefits must be balanced against the possibility of producing a neurological deficit. If tumour resection is carried out in the awake patient, the maximal tumour resection possible can be achieved whilst minimizing neurological dysfunction.

In the USA, the majority of these procedures are performed under local anaesthesia with sedation, and it has been suggested that this should be a standard approach to certain supratentorial tumours.[9] A shorter hospital stay and shorter use of high dependency facilities result in considerable cost reductions and some centres are even advocating day-case procedures.[10] In the UK, there is reluctance from both patients and surgeons to perform these procedures under local anaesthetic, and the depth of sedation required in many cases is associated with an increased incidence of complications. Over-sedation not only results in an uncooperative patient, but may also lead to respiratory depression. Any increase in Pa_{CO_2} may result in cerebral swelling.

Many anaesthetic techniques have been described for awake craniotomy. Neurolept analgesia is associated with excessive sedation and a higher incidence of pain and convulsions.[11] The patients in our first group were sedated using propofol infusions and several studies have endorsed this technique. Propofol was associated with a decreased incidence of convulsions but with a higher incidence of respiratory depression.[2] The use of the LMA has also been described previously for awake craniotomy.[3 7] When combined with a propofol infusion, it is well tolerated and provides a method of airway control in case of respiratory depression.

The combination of remifentanil and propofol has been used successfully for awake craniotomy, but in spontaneously breathing patients.[4 5] Remifentanil has a very short half-life, which is independent of the rate of infusion, and allows rapid control of the depth of anaesthesia. In addition, it provides greater haemodynamic stability. However, these patients also develop respiratory depression. We decided to use the respiratory depression produced by remifentanil to control ventilation to a desirable Pa_{CO_2} during the asleep period. The safety of the LMA for controlled ventilation has been the subject of recent discussion, but we have had no problems with its use in carefully selected patients.[12]

Patients who might benefit from awake neurological testing are selected by the neurosurgeon. Any potential medical problems are discussed with the anaesthetist who then contacts the patient for further review. A good rapport between the patient and the anaesthetist is essential. The only absolute contraindication to this technique is an uncooperative patient. Patients with oesophageal reflux,

Table 3 Comparison of incidence of complications in Group 3 with those in previous reviews (expressed as %)

Complications	Sarang and Dinsmore	Danks and colleagues[4]	Herrick and colleagues[5]	Archer and colleagues[10]
Pain	0	9.5	*	*
Seizures	5	4.8	18.9	16
Excess sedation	5	20	*	3
Agitation		9.5	*	*
Neurological deficits	5	9.5	*	*
Nausea and vomiting	0	*	13.5	8
'Tight' brain	0	*	*	1.4
Airway problems	0	*	*	*
LA toxicity	0	*	*	2

*No comment can be made on the incidence of these complications as data either not collected or not mentioned.

the very obese, and those with large vascular tumours all pose potential problems. If there are any doubts as to patient suitability, the decision to proceed is made after discussion between the anaesthetist, the surgeon, and the patient. The anaesthetic technique is then changed as necessary. Patients are counselled before the operation and have the opportunity to talk to other patients who have had an awake craniotomy. Those who decide to proceed with surgery tend to be very motivated and have a positive attitude to the whole procedure, which may also account for their quick recovery.

Despite our observations that the clinical conditions were superior in Group 3, poor record keeping and difficulty in assessing complications retrospectively made this difficult to prove. The most striking difference is the incidence of hypercapnia in Group 2 (Table 2). Interestingly, despite raised Pa_{CO_2} values in these patients with intracranial pathology, clinical conditions were thought to be acceptable in the majority of cases. However, the expectations of both anaesthetists and surgeons have changed over the years. Our surgeons now expect an awake and cooperative patient, and good intraoperative conditions. This was achieved in 95% of the procedures in Group 3, with high patient satisfaction (Marsh and Murphy, personal communication). All these patients were discharged within 1 week, with three discharged within 3 days. Our incidence of complications compares favourably with other groups (Table 3).

This report provides the largest series of cases of anaesthesia, as opposed to sedation, for awake craniotomy currently available in the literature. Despite the limitations of a retrospective review, we feel that we have now achieved a method of providing good operative conditions without compromising patient safety or acceptability. The prospect of day-case awake craniotomy is still remote, but with present day financial constraints and drives to increase patient throughput, awake craniotomy is a technique which will continue to grow in popularity.

References

1 Sahjpaul RL. Awake craniotomy: controversies, indications and techniques in the surgical treatment of temporal lobe epilepsy. *Can J Neurol Sci* 2000; **27** Suppl 1: S55–63

2 Herrick IA, Craen RA, Gelb AW, *et al*. Propofol during awake craniotomy for seizures: patient-controlled administration versus neurolept analgesia. *Anesth Analg* 1997; **84**: 1285–91

3 Tongier WK, Joshi GP, Landers DF, Mickey B. Use of the laryngeal mask airway during awake craniotomy for tumor resection. *J Clin Anesth* 2000; **12**: 592–4

4 Johnson KB, Egan TD. Remifentanil and propofol combination for awake craniotomy: case report with pharmacokinetic simulations. *J Neurosurg Anesthesiol* 1998; **10**: 25–9

5 Hans P, Bonhomme V, Born JD, *et al*. Target-controlled infusion of propofol and remifentanil combined with bispectral index monitoring for awake craniotomy. *Anaesthesia* 2000; **55**: 255–9

6 Huncke K, Van de Wiele B, Fried I, Rubinstein EH. The asleep–awake–asleep anesthetic technique for intraoperative language mapping. *Neurosurgery* 1998; **42**: 1312–16

7 Fukaya C, Katayama Y, Yoshino A, *et al*. Intraoperative wake-up procedure with propofol and laryngeal mask for optimal excision of brain tumour in eloquent areas. *J Clin Neurosci* 2001; **8**: 253–5

8 Meyer FB, Bates LM, Goerss SJ, *et al*. Awake craniotomy for aggressive resection of primary gliomas located in eloquent cortex. *Mayo Clin Proc* 2001; **76**: 677–87

9 Taylor MD, Bernstein M. Awake craniotomy with brain mapping as the routine surgical approach to treating patients with supratentorial intra-axial tumors: a prospective trial of 200 cases. *J Neurosurg* 1999; **90**: 35–41

10 Blanshard HJ, Chung F, Manninen PH, Taylor MD, Bernstein M. Awake craniotomy for removal of intracranial tumour: considerations for early discharge. *Anesth Analg* 2001; **92**: 89–94

11 Danks RA, Rogers M, Aglio LS, Gugino LD, Black PM. Patient tolerance of craniotomy performed with the patient under local anaesthesia and monitored conscious sedation. *Neurosurgery*1998; **42**: 28–34

12 Sidaras G, Hunter JM. Is it safe to artificially ventilate a paralysed patient through the laryngeal mask? The jury is still out. *Br J Anaesth* 2001; **86**: 749–53

13 Archer DP, Jocelyne MA. Conscious-sedation analgesia during craniotomy for intractable epilepsy: a review of 354 consecutive cases. *Can J Anaesth* 1988; **35**: 338–44