04 September 2015
No. 20

AWAKE CRANIOTOMY

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INTRODUCTION

The term “Awake Craniotomy” conjures up images of futuristic science fiction movies with intelligent aliens experimenting on unsuspecting astronauts! The technique, however, is not a new one. It was first described in its modern form in the 1950’s, when Wilder Penfield attempted to treat patients with intractable epilepsy. In fact, even the ancient Greeks used the technique of trepanation, albeit with a slightly more traditional form of anaesthesia: a wooden bite block and some ouzo! Although it is not commonly done in the public sector in South Africa, the technique has been gaining popularity with both patients and doctors alike, and aided by the newer anaesthetic agents and monitors, its rise is set to continue exponentially

The procedure represents a significant challenge to the neuroanaesthetist as we have to deal with walking the anaesthetic tightrope of keeping our patient deep enough to be comfortable, relaxed and immobile, while also ensuring they are light enough to protect their own airway and are able to be rapidly aroused. With a good knowledge of the scalp blocks and the wide range of pharmacological agents available however, it can be a very rewarding procedure for the anaesthetist, the neurosurgeon and the patient as well

WHY DO IT AT ALL? WHAT’S WRONG WITH A SLEEPING PATIENT?

A fully anaesthetized patient is certainly easier for us. We can control the airway definitively at the beginning of the procedure and then set about the tasks of keeping the patient in the optimal state of anaesthesia, analgesia and immobility. However the state of general anaesthesia is not adequate for the surgical needs. The broad indication for an awake craniotomy is to accurately perform functional brain mapping. This may require electrocorticography, direct cortical electrical stimulation or even asking the patient to perform tasks intra-operatively. None of these can be accurately performed in anaesthetized or even deeply sedated patients. Vitaz et al (1) compared the success rate of stimulating the motor cortex with electrocorticography in patients under general anaesthesia vs conscious sedation (which was then switched off before mapping began). Stimulation of the motor cortex was elicited in 100% of the awake patients vs 50% of the patients under general anaesthesia ($p<0.001$). Furthermore, the mean current used to achieve stimulation was 5mA in the awake group and 13mA in the anaesthetized group and this was the likely cause of a trend towards higher seizure rate in the patients under general anaesthesia (29% in GA vs 10% in awake $p>0.05$).

The presence of an awake patient who can respond in real time to any stimulation of brain tissue provides an intuitive measure of safety when tumours must be excised within close proximity of critical cerebral structures. Theoretically, surgeons should be far more accurate in their resection of a tumour and an epileptogenic focus when they have a patient who they can interact with. Unfortunately, there have been no large, high quality randomized control trials performed to prove or disprove this hypothesis, and as such, data on the safety of the procedure is based almost entirely on cohort studies and retrospective reviews. Sacko and colleagues (2) compared the total resection rate and postoperative cognitive deficits in a cohort study of 575 patients undergoing either general anaesthesia or awake craniotomy. The findings showed a significantly improved resection rate of lesions in eloquent areas (37% vs 14% p<0.05) and fewer permanent neurological deficits (4.6% vs 14% p<0.001). Despite being a retrospective trial (and thus without any randomization), the groups compared were well balanced in terms of baseline characteristics and there was no statistical difference in the pre-op period in terms of neurological deficit or tumour location (p=0.65). It was also the largest individual trial comparing the two techniques.

Reithmeier's group (3) compared the clinical outcome and post-op MRI images of 42 patients operated on by awake craniotomy (using neurophysiologic monitoring) with 28 patients who had similar lesions and were operated on under general anaesthetic, without the monitoring. The patients who had an awake procedure had a significantly improved resection rate on MRI (tumour rest present in 27% vs 52% p=0.04) and an improvement in clinical outcome. Unfortunately details about the baseline characteristics of the patients in the groups was not supplied and the impact of the study is further hindered by the small sample size and the chronology bias in that the patients done under general anaesthetic were done between 1994 and 1997 whereas the awake patients were operated on between 1997 and 2000. Duffau's group (4) published a similar, although much larger trial in 2005.

Here, 100 patients operated on under general anaesthetic between 1985 and 1996 were compared to 122 patients operated on under awake craniotomy between 1996 and 2003. The rate of post-operative dysfunction and the quality of resection were compared between the 2 groups. Even though more patients from the awake group had tumours resected from eloquent areas (more difficult resections with typically worse outcomes), they had better post-op outcomes in terms of mortality (2% vs 0%), severe permanent deficit (17% vs 6.5% p <0.019) and MRI results. Unfortunately this study also suffers from chronology bias.

De Benedictis showed that low-grade gliomas which had previously been incompletely excised under general anaesthetic could be subsequently completely excised when using awake mapping techniques.(5) In this case series, 9 patients had undergone excisions of low-grade gliomas in functional areas but this had resulted in only partial or subtotal resections. A second craniotomy was then performed in the awake condition and the extent of resection was improved in all cases, with 5 patients having complete excision. There was no permanent neurological worsening as a result.

The benefits of awake craniotomy were not seen in all studies. Gupta et al (6) conducted what is still the only randomized control trial comparing the two different techniques. Patients in the general anaesthetic group had a higher percentage of complete tumour resection (63%) than the awake group (47%). The immediate post-op outcome was also better in the general anaesthetic group, with 10% of these patients and 38% of patients in the awake group exhibiting post-operative motor deficits. The surgical time was longer for the awake craniotomy and there was more intra-operative bleeding. Closer examination of the trial however, reveals several design flaws. Firstly, it was very small (only 53 patients in total) and as such, none of the above-mentioned signals reached statistical significance.

The immediate post-operative outcome difference between the groups was even less noticeable at three month follow-up with 3 awake patients vs 2 general anaesthetic patients exhibiting signs of motor deficits. Furthermore, the awake patients did not have electrocorticography or direct electrical cortical stimulation performed on them – they were asked to perform tasks intra-operatively and if at any time a deficit developed, the surgery was terminated, even if visibly abnormal tissue was seen in that area.

Thus the patients were not allowed the full benefit of an awake technique. The concern about the length of the procedure being longer in awake craniotomies is not borne out in any other studies; a systemic review of 8 trials conducted by Brown et al (7) showed that all other trials reported shorter operating time in awake patients. The increased length of time as well as the increased blood loss suggests perhaps that the surgeons involved in the study were inexperienced with the procedure.

It seems then that we haven't been able to fully answer the question of which technique is the most effective for tumour removal and as such, this area represents fertile ground for good quality future research.

The data for length of stay in hospital is far more convincing in favouring an awake technique. The systematic review mentioned above including a total of 951 patients showed a dramatic drop from 9 days to 4 days with the move towards an awake technique. (7) Thus these patients are less at risk of nosocomial infections, deep venous thromboses, and pressure ulcers and represent a much reduced cost to the health service both in terms of money and resources. The reason for the considerable decrease is not entirely clear. It is proposed that the awake patients do not have as long a post-operative recovery period as less anaesthetic agent is used and because post-operative analgesia is far easier. Both of these will also lead to a reduction in post-operative nausea and vomiting. There is a lower incidence of post-operative ICU requirements even in patients with similar tumours in terms of size and location. These factors then have a knock-on effect meaning fewer post-op complications (including pulmonary complications) and thus less need for prolonged hospitalization.

At the extreme end of this reduction in hospital days lies the concept of day case surgery and there are now several centers around the world performing awake craniotomy as a day-cases. As long as the patients are properly selected, the results of day case surgery are very good. A study from as early as 2001(8), showed of the 46 patients selected for day-case awake craniotomy (for metastasis excision, glioma excision and "miscellaneous surgery"), 41 were able to be discharged post-op and only 1 patient required re-admission for headaches after going home.

Reviews of patients' perspectives of awake craniotomy are overwhelmingly positive. (9-13) Patients report feeling confident pre-op, comfortable intra-op and are particularly pleased with the minimal post-op pain and early discharge that an awake technique allows. 80-90% of the patients described feeling satisfied with the procedure as a whole. Wrede et al (13) compared patients' experiences of general anaesthesia vs awake techniques and found that patients who had an awake craniotomy were more satisfied with the peri-operative course than their anaesthetized comparative group.

WHICH PATIENTS ARE SUITABLE FOR THIS PROCEDURE?

Traditionally, awake craniotomy was performed only for epilepsy surgery and that is the indication that most people are familiar with, however operative techniques have advanced to enable us to perform an awake technique for a host of other pathologies.

Firstly, there are anatomical reasons for us to favour an awake technique. The eloquent areas of the cerebral cortex are those involved in linguistic ability, senses and motor functions. Space-occupying lesions in these areas are now routinely excised using awake craniotomy, providing reassurance to the neurosurgeon that no vital functions are being compromised by the surgery. Also, an awake patient can facilitate accurate intra-operative mapping of the tumour and the normal brain tissue, to ensure precise margins of excision. Both supratentorial tumours as well as brain stem lesions may lend themselves to excision by awake craniotomy.

Secondly, there are physiological reasons. Movement disorders such as Parkinson's disease, essential tremor, dystonia and even psychological disorders such as obsessive compulsive disorder can be treated by Deep Brain Stimulation. In this procedure, electrode implants are inserted into the thalamus, the subthalamic nucleus or the globus pallidus. For successful placement of the implants, as well as accurate MRI, CT and 3D computer mapping, the neurosurgical team require an alert, awake and attentive patient who is able to follow commands and co-operate fully.

Finally, there are pharmacological reasons to opt for an awake craniotomy rather than a general anaesthetic. For accurate delineation of epileptogenic foci, intra-operative electrocorticography is required. All anaesthetic agents affect the electrical signals detected during this mapping and as such, an awake patient confers an advantage for accurate resection. (14)

There are also several contra-indications for performing an awake craniotomy rather than an asleep procedure. Patients who are confused, unable to communicate adequately, unable to lie still for a prolonged length of time or extremely anxious are clearly not suitable for a procedure that requires a high degree of patient co-operation. A lesion in the lower occipital region would require the patient to be prone for a significant length of time and thus it is not advised to perform the procedure on an awake patient. If the tumour involves a large area of dural tissue, it is also preferable to have the patient fully anaesthetized, as the dura is a very sensitive structure and it is not blocked by the scalp blocks, but rather by local anaesthetic-soaked pledglets. Obstructive sleep apnoea represents a relative contra-indication to awake craniotomy as airway maintenance and titration of sedative medication becomes problematic.

Intuitively, we would assume that it would be absolutely contra-indicated to perform an awake craniotomy on paediatric patients. However, the literature is overflowing with case reports of successfully performed awake procedures on minors. Klimek and Verbrugge even described the successful completion of the procedure in a 9 year old boy who had his father present in the theatre throughout the procedure.(15) Age alone is therefore not a contra-indication, but the patient should be adequately prepared pre-op and be of adequate psychological and mental maturity.

WHAT ARE THE ANAESTHETIC OPTIONS FOR AWAKE CRANIOTOMY?

There are two main options for the anaesthetic for awake craniotomy: Monitored Anaesthetic Care and the Asleep, Awake, Asleep technique.

Monitored Anaesthetic Care (MAC) consists of a conscious sedation during the initial stimulating parts of the procedure (such as the nerve blocks), followed by a pause in sedation during cortical mapping and then the sedation is restarted again before the surgeon begins to close the dura. The patient maintains his or her own airway throughout the procedure and the sedation is titrated to maintain haemodynamic and respiratory functions. The patient is often placed on supplemental oxygen.

MAC was initially performed using neuroleptanaesthesia but following a paper by Silbergeld in 1992 which described the use of propofol sedation (16), most centers around the world began using propofol, owing to its rapid onset/offset characteristics, accurate titratability and lack of hangover effect. It also has potential anti-emetic properties which increase its usefulness in this patient group especially. Propofol is commonly run as a TCI with effect site concentrations of 1-2µg/mL or as TIVA with rates of 2-3mg/kg/hr.(17) Herrick also suggested a patient-controlled sedation with propofol was a viable alternative, with his patients receiving a basal infusion of propofol but having the ability to self-titrate their sedation using a PCS device. (18) He did report an increased incidence of transient respiratory rate depression (respiratory rate <8bpm) in the PCS group compared to the control group (sedated with droperidol and fentanyl infusion), but attributed this to the boluses of fentanyl given in the propofol group. Propofol was shown to not interfere with electrocorticography if stopped 15 minutes before mapping in adults (19) and 20 minutes before mapping when used in children (20) and as such represents a very useful agent.

The choice of which opioid to give in conjunction with propofol appears to vary dependent on the preference of the anaesthetist doing the case, with very little good evidence to suggest any one agent over the others. Remifentanil, with its rapid and accurate titratability has gained much support in the recent literature. It is usually used as a TCI with effect site concentrations ranging from 1-3ng/mL or infusion rates of 0.05-0.1µg/kg/min. (17) All opioids selectively activate inter-ictal epileptiform activity, which causes a negative interference during tumour surgery, and as such, the opioid infusion is stopped in time to allow full dissipation of clinical effect before the tumour mapping is done. Remifentanil's short context-sensitive half-time makes it a logical choice in this setting.

In contrast to tumour surgery, the same property of stimulation of EEG activity is occasionally used to assist the surgeon in locating the epileptogenic focus in epilepsy surgery. In a study by McGuire et al, the electroencephalographic activation effect of alfentanil was compared with that of remifentanil. It was found that an equipotent dose of alfentanil caused an increase in activation from baseline of 99.8% compared to remifentanil's 67.4%. The authors concluded that alfentanil was the better opioid for activation of intraoperative electrocorticography. (21)

MAC craniotomy has also been successfully completed in the complete absence of opioids, although this is more common with the AAA technique described below.

Asleep Awake Asleep (AAA) is a technique which involves a full general anaesthetic at the start of the procedure, with the need for active airway management. The scalp blocks are performed and the procedure is commenced. Before tumour mapping begins, the anaesthetic is stopped, the patient is woken up and the airway device is removed. The patient is re-anaesthetised before dural closure and the airway device is reinserted.

The technique was initially described by Penfold in 1954 who used a blind nasotracheal intubation to secure the airway after cortical mapping. Several other approaches used at the time involved leaving the patient intubated throughout the case, but still ensuring a completely awake patient during the mapping process. Hall (22) used a succinylcholine infusion to keep patients immobile yet fully awake and Ingvar administered local anaesthetic into the airway via a small multi-holed catheter. Not only were these techniques undoubtedly uncomfortable for the patients, but they left the patient unable to communicate with the neuropsychologist or anaesthetist and as such, a valuable monitor was lost.

More recently, the advent of the laryngeal mask airway has made the AAA technique significantly easier to perform. The LMA can be easily inserted without the anaesthetist needing to move to the sterile surgical side of the operating theatre, without the need for a laryngoscope or head extension and with significantly less coughing and gagging, and yet it still provides a reliable airway in most patients. (17, 23, 24) Chen even explored the insertion of an LMA in the lateral position after cortical mapping in awake craniotomy and found a success rate of 90%, with the remaining 10% of patients all being successfully ventilated by facemask until the completion of the procedure.(25) Shinokuma’s group described the AAA technique leaving the LMA in situ throughout and still described clearly audible and comprehensible phonation.(26) Several other devices have been successfully used, from non-invasive ventilation by facemask, to nasal BiPAP to a cuffed oropharyngeal tube. As such, the modern neuroanaesthetist has several tools at his/her disposal for both first-line and back-up airway control.

The AAA technique is usually performed with a Propofol TIVA or TCI as a hypnotic in combination with a short acting opioid. Many authors have suggested propofol is superior to a volatile agent because of its anti-emetic effect in comparison to the volatile and also because of its upper airway effects which facilitate a smooth LMA insertion without coughing or bucking. However there is a paucity of hard evidence to support this and many centers use desfluorane in its place as a maintenance agent.

The AAA technique offers superior airway control to MAC and does not require as delicate a titration of anaesthesia, but it does present additional challenges, in terms of secretion management and particularly with re-anaesthetising a patient having only limited access to an airway which is often not optimally positioned for the anaesthetic needs.

Both AAA and MAC anaesthetics have similar goals of

1. Maintaining patient co-operation: Adequate analgesia, sedation and anxiolysis in combination with comfortable positioning
2. Prevention of haemodynamic and respiratory compromise: Maintaining a safe airway with adequate minute ventilation and haemodynamic stability even during stimulating periods of the procedure
3. Prevention of complications: Prevention of nausea and vomiting as well as seizures.
4. Limited or no interference with cortical mapping and electrophysiological recordings.

Dexmedetomidine is becoming widely used, both for sedation in the MAC technique and as an adjunct in the AAA technique. Its properties of good sedation without respiratory depression along with analgesia make it a very useful drug for an awake craniotomy. In the only randomized control trial comparing it to propofol, dexmedetomidine compared favourably in terms of “time to adequate revival”, “quality of revival” and surgical satisfaction. There was no difference between the groups with regards to patient satisfaction or adverse events.(27) Unfortunately this was a small trial of only 30 patients. Several other case reports attest to the safety and utility of dexmedetomidine. Some report stopping the infusion 10 minutes before neuro-functional testing, but several case series describe leaving the infusion running at 0.1-0.2μg/kg/min during the neuro-functional testing and report a very lightly sedated, co-operative patient and no interference with brain mapping.(27-31)

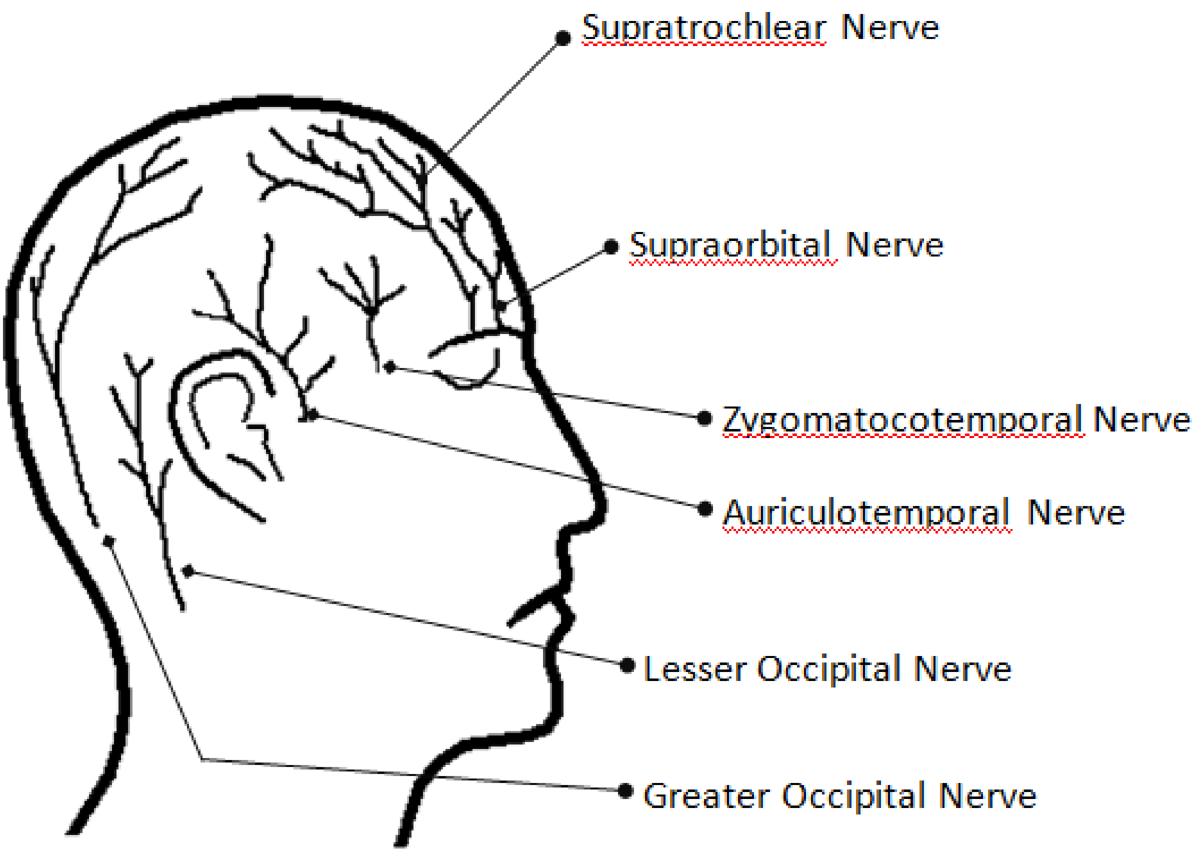
HOW DO YOU DO A SCALP BLOCK?

Much like the importance of a well topicalised airway for an awake fibreoptic intubation, the scalp block is an essential part of the anaesthetic for an awake craniotomy. Fortunately, it is fairly easy to do – it simply requires some practice!

The block is usually done with the patient already anaesthetized (or sedated, depending on which anaesthetic technique you are using). This is because several injections are needed and so the procedure is painful. The technique has been described in completely awake patients, using EMLA™ cream to pre-anaesthetise the injection sites, but this needs to be considered in advance to ensure enough time for the EMLA™ to work.

Several of the injection sites are in close proximity to large arteries and veins, and so it is important to ensure that the local anaesthetic solution is not administered into a vessel as this may have dire consequences. Also, clinical vigilance is necessary as the scalp tissue is highly vascularised and systemic levels of local anaesthetic may rise rapidly even after correct placement of the injections. Two separate studies by Costello et al (32, 33) investigated the rise in plasma levels after scalp blocks using ropivucaine (in 2004) and then levobupivucaine (in 2005). These studies both found a marked rise in serum concentrations of the respective local anaesthetics, despite the correct placement of the injections and the use of adrenaline in the mixture. The peak concentration of levobupivucaine was reached in 12minutes and that of ropivucaine was reached in 15minutes. In neither study did any of the patients experience symptoms of local anaesthetic toxicity, but the recommendation made on the basis of these two studies is that patients should be closely monitored for any signs of toxicity particularly for the first 15minutes after the scalp block.

The scalp block is performed using between 40 and 60ml of a local anaesthetic mixed with 1:200 000 adrenaline, as this decreases the rate of rise of plasma concentration as well as increasing the duration of the block. A long duration of anaesthesia is vital as an awake craniotomy may take as long as 8 hours or even longer to complete. Bupivucaine (0.25-0.5%) has been used for decades in scalp blocks without a single case report of local anaesthetic toxicity. Nevertheless, fears of high systemic levels have persuaded most recent authors to suggest that levobupivucaine (0,5%) or ropivucaine (0.75%) are superior agents. (17, 34, 35)



There are 6 nerves that need to be blocked on each side of the head.

1. The **supraorbital nerve** is a branch of the trigeminal nerve (V1) and innervates the anterior part of the forehead and top of the head. It is blocked as it exits the supraorbital notch (on the supraorbital ridge at the junction of the medial 1/3 and lateral 2/3). The notch is palpated, the needle inserted perpendicular to the skin and the local anaesthetic is deposited just superficial to the periosteum. It is a shallow block.
2. The **supratrochlear** nerve (also originating from the ophthalmic branch of the trigeminal nerve) also innervates part of the forehead and anterior scalp. This arises about 1-1.5cm medially to the supraorbital nerve and is usually blocked by directing the needle medially from the same injection site as the supraorbital nerve.
3. The temporal branch of **the auriculotemporal nerve** is blocked by an injection immediately posterior to the superficial temporal artery, and 1cm anterior to the auricle, above the level of the temporomandibular joint. The injection is superficial and subcutaneous – a deep injection will result in a facial nerve block.
4. The **zygomaticotemporal nerve** innervates a small area of forehead as well as the temporal area. It passes through the temporalis muscle and then enters the temporalis fascia at the lateral border of the orbit. It is therefore anaesthetized using a superficial field block from the lateral border of the supraorbital margin down to the distal zygomatic arch as well as with a deeper injection through the temporalis muscle and just superficial to the periosteum of the temporal bone. This is important for temporal flap incisions.
5. The **lesser occipital nerve** innervates the scalp posterior to the auricle. It ascends along the posterior border of the sternocleidomastoid muscle and can be blocked by injecting either superficially or deep to the fascia at the uppermost posterior border of this muscle. Another technique suggested is to inject the local anaesthetic superficially in a line from the inferior to the superior poles of the auricle and then to

continue to inject superficially along the superior nuchal line [1] to the greater occipital nerve.

6. The **greater occipital nerve** innervates the posterior part of the scalp and also variably the top of the scalp and the auricle. It is blocked with an injection immediately lateral to the occipital artery which can be felt 3cm lateral to the external occipital protuberance, along the superior nuchal line. Alternatively, a subcutaneous injection along the middle third of a line between the mastoid process and the external occipital protuberance along the superior nuchal line will provide anaesthesia if the occipital artery cannot be palpated.

PERI-OPERATIVE EVENTS

In order to provide the optimal anaesthetic to our patients, we need to have a good idea of the course of events in the peri-operative period.

Pre-operative

The patient is selected appropriately as indicated above and is prepared psychologically by all team members, including the neurologist, neurophysiologist, neurosurgeon and the anaesthetist.

A standard anaesthetic history and examination is appropriate, with particular emphasis placed on the underlying condition (eg epilepsy) as well as any potential difficulty with the airway.

There is no consensus regarding premedication for an awake craniotomy. Several groups do not routinely prescribe any premed for their patients. (19, 36-38) Those who use pharmacological anxiolysis suggest midazolam (17, 39, 40) as it has a rapid onset and a short duration of action. Arguments have been made against benzodiazepines as they are synergistic with opioids in producing respiratory depression and cause a reduction in pharyngeal tone as well as influencing cognitive functioning and decreasing epileptic foci (which may be detrimental in some procedures). Recently, Clonidine in a dose of 2-3µg/kg orally 1 hour pre-op has been used with good effects. (17) This has a more favourable pharmacological profile than the benzodiazepines.

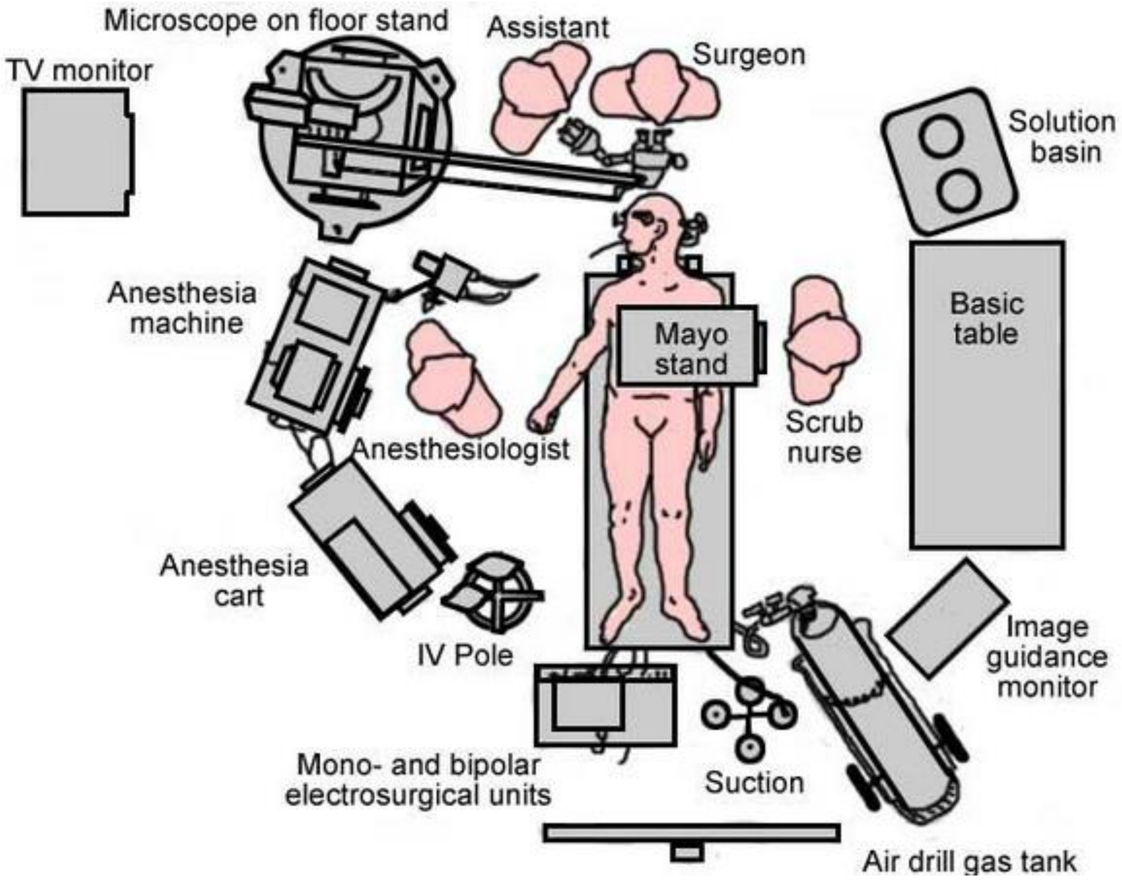
An antisiaologogue may also be administered, but the adverse effect of patient discomfort must be weighed against the benefit of a reduction in secretions.

[1] The superior nuchal line is a ridge of bone that curves from the external occipital protuberance to the temporal bone. Above this line, the bone feels smooth and is covered by the occipitofrontalis muscle and below the line, it feels rough and serves as the attachment site of multiple muscles, including the semispinalis capitus, trapezius, occipital belly of occipitofrontalis and posterior border of the sternocleidomastoid. Posteriorly it can be thought of as the most inferior part of the occipital bone that is palpable!

Prophylaxis against acid reflux (in the form of a well-timed dose of an H2-receptor antagonist or proton pump inhibitor) is advocated by many sources.

Patients presenting for tumour surgery should have their routine anticonvulsant medication prescribed, but those coming for deep brain stimulation or epilepsy surgery need to have their case discussed individually with the neurologist and neurosurgeon as the anticonvulsant may affect intra-op functional mapping or accurate location of epileptic foci. (41) The benefit of better electrocorticography recordings needs to be weighed against the potential harm from intra-operative seizures.

The standard operating theatre preparation is acceptable, but attention must be paid to ensuring that all necessary airway tools are ready and in working order, as any airway problem intra-operatively has the potential to be very difficult to manage because of the limited access to the patient. Generally, the theatre is set up with the anaesthetic machine at the foot of the bed or at the side, facing the patient. The patient is in the lateral or supine position facing the anaesthetist and the neurophysiologist. The surgeon and scrub sister are at the top of the bed.



<u>Intra-operative</u>

Patient positioning is an important aspect of care of the awake craniotomy patient. It is advisable that patients position themselves on the operating table initially, as this will assist in placing them in the most comfortable position. The operation is a long one and the patient may be awake for a prolonged length of time, therefore good positioning is essential in aiding good patient co-operation. The operating table should be adequately padded and special attention needs to be paid to the positioning of the head and upper limbs.

All standard ASA monitoring is required for awake craniotomy. In addition, it is very useful to attach the capnograph tubing to the nasal cannulae or facemask if the MAC technique is chosen. This is used primarily as a monitor of respiratory rate and to detect apnoea, as absolute the CO2 values detected are likely to be far lower than the true value owing to the mixing of gases in a circuit which is open to the environment. (34)

Arterial lines and central venous catheters are no longer routinely sited but may still offer some advantage, particularly in patients with other co-morbidities.

Depth of anaesthesia monitoring (eg BIS™, Entropy™) is also often used to guide sedation and anaesthesia (42), although there appears to be a paucity of good evidence suggesting patient-specific benefits.

Induction of anaesthesia or conscious sedation then ensues and the scalp block is performed. If the surgical team decides to use a Mayfield head fixator, this should either be applied after the scalp block or with the use of local anaesthetic at the pin sites.

Once the dura is opened, the anaesthetic needs to be lightened before the electrocorticography, direct cortical electrical stimulation or neuro-functional testing is done.

Electrocorticography is recorded from electrodes placed on the cortex, either superficial or deep to the dura. The electrodes measure local field potentials and thus can identify epileptogenic foci and it does this with far greater accuracy (spatial resolution) than scalp electrodes.

Direct cortical electrical stimulation is frequently done in concurrence with the electrocorticography but may also be done in isolation. A current is applied to a section of the cortex and the surgeon then watches for the result: for example in the resection of a tumour near the motor cortex, the adjacent areas responsible for movement of the various parts of the body can be mapped out and identified by observing the motor response to the current. Then the nearby tumour (which would elicit no motor response) can be safely excised.

Another form of functional brain mapping is neuro-functional testing. A full description of this topic is beyond the scope of this article, however it is important for anaesthetists to be aware of what is done as this may impact the anaesthetic technique and also, in rare circumstances, the anaesthetist may be required to assist with relaying responses to the surgeon. Typically, the testing is performed by a neurophysiologist or even by the patient's neurologist (who will be most familiar with any pre-operative deficits). The testing done is naturally related to the area of the cortex that is being operated on or mapped out.

- Frontal lobe testing may involve motor functioning (eg moving upper limbs), speech (such as asking the patient to count), semantic tasks of association and judgement and picture naming tasks.
- Parietal lobe function involves sensori-motor functions, calculations, picture naming and an assessment of working memory
- The Temporal lobe is assessed with semantic tasks of association and judgement, reading, visual field, picture naming and functions of working memory.
- Occupital lobe function is assessed by tasks such as picture naming, reading and visual fields

- The Insular region is assessed using picture naming tasks, working memory and sensori-motor functioning.

After completion of the mapping and the surgery, the patient is re-anaesthetised or re-sedated (depending on anaesthetic choice) before the dura is closed. The patient may need to have an LMA reinserted.
At the completion of skin closure, the patient is woken up and extubated.

Post-operative

Post-operatively, the patient is moved to either a High Care unit or a specialized unit within the neurosurgical ward for the first 12-24 hours. It is vital that the patient is well monitored for any signs of complications of the anaesthetic or the surgery. Post-operative haematomas may develop (especially in the first 6 hours post-op) and may necessitate re-operation. (42)

Post-operative pain is usually minimal and treated with simple analgesics and only the occasional opioid dose if required.
Patients are usually discharged on the 2nd or 3rd post-operative day although some units perform awake craniotomy as a day-case procedure.

WHAT COMPLICATIONS SHOULD THE ANAESTHETIST BE AWARE OF?

There are several complications that the neuroanaesthetist should be on the alert for, and be prepared to treat rapidly in order to ensure a successful surgery. They are divided into the anaesthetic complications and the surgical ones.

Anaesthetic Complications

1. Loss of airway / desaturation. This is particularly a problem with the MAC approach and an over-sedated patient, but can also be a problem with an abnormal head/neck position causing a leak around the LMA or additionally with failed insertion of LMA after cortical mapping and re-anaesthetising of the patient. This is not the ideal case for the occasional sedationist! Oversedation may lead to an airway that is very difficult to manage. Failure to place an LMA (either as a rescue in the MAC approach or as the chosen airway in the AAA technique) may require endotracheal intubation. This is done by the surgeon removing the clamps on the skull, covering the brain with a sterile drape and holding the head in an appropriate position. The anaesthetist then needs to intubate the patient without compromising the sterility of the procedure. This requires experience and expertise as well as good co-operation between the surgeon and the anaesthetist. It is important to ensure that all necessary airway tools are in theatre to facilitate a difficult endotracheal tube placement – particularly a fibreoptic scope.
2. Pain. Scalp blocks usually suffice for good analgesia, however they do not cover all the potentially stimulating areas. Traction on the dura and on any of the vessels (such as the middle meningeal artery and saggital sinus) may cause pain. This is usually treated with local anaesthetic-soaked pledglets or alternatively, increased sedation and gentle surgical technique. Equally, the sound of the craniotome is conducted incredibly well by the bony framework of the skull and while the sawing will not cause pain in a well-blocked patient, the sound can be very disturbing. Increased sedation at this point in the procedure is important for the patient under MAC anaesthesia.

3. Nausea. This is both a frequent and important adverse event, caused not only by the anaesthetic but also because of traction on the dura and blood vessels. It is therefore important to provide prophylactic anti-emetics and many authors recommend a propofol infusion rather than a volatile-based anaesthetic. Nausea from surgical stimulation is difficult to treat pharmacologically and may only be relieved by decreasing the surgical stimulation.(19)
4. Anxiety. Patients need to be very well prepared for all intra-operative events and also need to be selected appropriately for the procedure. Intra-operative reassurance combined with good pre-medication and anxiolysis are very important to ensure a co-operative patient.
5. Shivering. This involuntary movement is disturbing for the patient and the surgeon as well as increasing myocardial and cerebral demand for oxygen and sympathetic outflow. It is important to have a warm theatre, use in-line fluid warmers and forced air warming device as these procedures are often very long. Dexmedetomidine as well as meperidine have been used to abort the shivering.
6. Haemodynamic disturbances. Labetalol should be on hand to treat any increases in blood pressure or heart rate. Any trigger (pain, anxiety) should be treated. Bradycardia may occur secondary to stimulation of the trigeminal nerve and should be treated with cessation of surgical stimulus and an anticholinergic. Major blood loss is uncommon.
7. Local Anaesthetic Toxicity. Although rare (as yet, no published case reports in awake craniotomy patients), this may be catastrophic. Early and aggressive resuscitative measures along with Intralipid™ are essential.

Surgical Complications

1. Seizures. The incidence of these is variable in the different case series but nonetheless relatively common (up to 16% in one case series). (43) Seizures are more common when neuroleptanaesthesia is used and less common with the use of propofol and remifentanil. (17, 38) An Ojemann stimulator is used to perform the functional mapping and it is during this phase that seizures are most frequently encountered, especially when using the stimulator over the motor cortex. The treatment of choice is iced saline lavage of the brain. If this fails, a bolus of propofol should be given in preference to midazolam as the former will lead to a more rapid return of accurate electrocorticography.
2. Venous Air Embolism. Awake craniotomies are usually performed in the lateral or supine position, and as such the incidence of venous air embolism is rare. Occasionally, however, the procedure is done with the patient sitting or in a semi-sitting position. This combined with spontaneous respiration (using negative pressure to ventilate), means the patients are at increased risk for this complication. The anaesthetist should be alerted by a rapid drop in end-tidal carbon dioxide or cardiac output or signs of right heart obstruction and provision should be in place to swiftly move the patient to the supine/ head down position should CPR be required.
3. Cerebral Oedema. This is usually not a major problem, but may require head-up positioning or mannitol infusion.
4. Bleeding. Rare

WHAT DOES THE FUTURE HOLD FOR THE AWAKE CRANIOTOMY?

Despite having been practiced for over 60 years, there are still many unanswered questions around the practices involved with awake craniotomies. While complications appear to occur only rarely, enough of these procedures are being done in centers in the developed world that large randomized control trials are indeed feasible. The data obtained from these will undoubtedly be very useful in improving outcomes for our patients. Nevertheless there appears to be enough data to suggest that there are certainly some benefits from the technique. In fact, it has been questioned whether it is even ethical to randomize patients away from an awake technique in several scenarios.(2) Not only do patients spend fewer days in hospital (sometimes less than 1 day!) and have an overwhelmingly positive experience of the procedure, but the weight of evidence suggests that the complication rates in terms of post-operative cognitive deficits are lower when the patient is allowed to interact with the surgical team. In all but 1 trial, the percentage of tumour excision was higher in awake craniotomies than in those using an asleep technique. Also, it appears that tumours that we were previously unable to excise are made amenable to resection by the fact that we can monitor our patient’s responses in real-time.

With advances in pharmacology and medical technology the awake craniotomy will likely become far easier for the anaesthetist and probably safer for the patient too. We have already seen the impact made by drugs such as Dexmedetomidine, with its ability to provide anxiolysis, sedation and analgesia without suppressing the respiratory drive. Levobupivucaine and ropivucaine appear to confer increased safety in the event of local anaesthetic toxicity. TCI pumps allow better titration of our infusions and depth of anaesthesia monitors give us a better idea of the target organ effects. The development of a vast array of airway devices has made airway management significantly easier as well. This trend is only likely to continue rising.

As such, the technique of performing an awake craniotomy is continually changing and advancing with new developments. The rate at which the procedure is performed also appears to be on the rise. So perhaps for now you can keep this little booklet stored away in the region of your shelf assigned to “will read for interest once the exams are over”, but don’t forget it altogether: the technique is not one for advanced intelligent aliens in single-piece silver jumpsuits, it is happening every day in centers all over the world, and you may be called to perform one sooner than you imagine!

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