Awake Craniotomy: A Practice Overview

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Craniotomies are a common neurological intervention for intracranial tumor resections. Anesthesia techniques allow surgeons to aggressively and optimally resect neoplastic tissue while sparing normal cerebral tissue. Awake craniotomies are surgical techniques that enable surgeons to avoid damaging normal cerebral regions and allow real-time patient feedback. Such surgical interventions would not be possible without anesthesia. The role of anesthesia providers is critical in gaining the trust and motivation of the patient. Preoperative evaluation, regional anesthesia, general anesthesia, and monitored anesthesia are necessary to achieve a successful surgical intervention with awake craniotomy. As awake craniotomy gains more popularity, dependable anesthesia techniques remain critical. A discussion follows of the role of anesthesia providers in awake craniotomy during the entire perioperative continuum.

Keywords: Awake craniotomy, Broca area, cortical mapping, scalp block, Wernicke area.

Introduction
Anesthesia providers are familiar with the gross anatomy of the human brain, ie, the cortex, midbrain, and brainstem. However, within the cerebral cortex, the anatomical locations of the highly functional components are much more variable. It is the unique location of these areas in each person that poses a challenge in modern neurosurgical procedures. The areas of the cortex that contain speech and language centers and the motor strip are termed eloquent. More specifically, these areas include the Broca area, Wernicke area, arcuate fasciculus, insular brain, and motor and sensory cortices of the brain.1,2 The Broca area is responsible for speech production and language processing, whereas the Wernicke area is mainly responsible for language comprehension. The arcuate fasciculus is a bundle of neurons that transfers information from these areas. The insular brain is a complex, subcortical structure involved in the perception of pain, emotion, self-awareness, speech articulation, motor skills, and other functions.

Specialized imaging techniques can locate some criteria...
cal areas of the brain, but the techniques are somewhat imprecise. Only 50% of areas relevant to speech located by direct stimulation coincide with magnetic resonance imaging results.3 Awake craniotomies are often used to identify and, thus, avoid the eloquent areas of the brain that allow speech, motor, and vision functions. During an awake craniotomy, a patient is conscious as the surgeon stimulates different areas of the brain while asking the patient to perform certain tasks. With the patient awake, the eloquent areas of the brain can be precisely mapped before tumor resection.4 This mapping minimizes the risk of new functional deficits developing postoperatively and allows for aggressive resection of the tumor and, thus, better neurological and oncological outcomes.5,6 Negative cortical mapping results are associated with a decreased risk of postoperative deficits.5 With positive cortical mapping results, less of the tumor may be safely resected because of the proximity or involvement of the eloquent area, causing an increased risk of neurological deficits and poor outcomes.5,7

According to a study at The University of Texas MD Anderson Cancer Center, Houston, reported by Kim et al1 in 2009, tumor histologic features, tumor location, and preoperative deficits did not prove to be predictors of neurological outcome, whereas cortical mapping results, the extent of the resection, and intraoperative neurological changes were all predictors of neurological outcome. With an average of 75 awake craniotomies performed each year at the MD Anderson Cancer Center, the anesthesiology team combined its experience with findings in the current literature to develop an evidence-based practice that regularly enables patients to be cooperative, alert, and oriented, and facilitates cortical mapping.

Anesthetic Objectives for Awake Craniotomies
The primary anesthetic objectives of an awake craniotomy are to allow for accurate cortical mapping of the eloquent cortex and to maximize patient comfort. To achieve these objectives, anesthesia providers must maintain hemodynamic stability and adequate ventilation throughout the entire procedure.5 In addition, prevention of nausea and vomiting is paramount because any increase in intracranial pressure may cause subsequent brain edema and associated detrimental effects.8

Different approaches to achieving these objectives may be used. The awake craniotomy is effectively divided into 3 segments: preparation and pinning, cortical mapping, and resection and closure. Anesthetic techniques have been developed to meet the needs of each stage. These techniques include a monitored anesthetics care (MAC) technique throughout the entire procedure and an asleep-awake technique or an asleep-awake-asleep technique, with or without use of a laryngeal mask airway (LMA).

The monitored anesthesia care and asleep-awake-awake technique involve continuous intravenous sedation while the patient breathes spontaneously during a portion or all of the procedure. However, without the ability to control ventilation, the potential for hypercapnia due to sedation often makes surgical exposure less than optimal. It is for this reason that the asleep-awake-asleep technique, with the use of an LMA, is the most widely used technique at the MD Anderson Cancer Center. The use of an LMA allows anesthesia providers to augment ventilation and avoid hypercapnia and hyperventilation.4 Use of an LMA also facilitates greater depth of anesthesia during the painful components of the surgery and while the scalp block is performed.9 Once the surgeon is ready for mapping, all sedation may be discontinued, allowing the patient to be as alert and responsive as possible.

Regardless of the technique used, anesthesia drugs that rapidly dissipate are the most desirable. Infusion techniques using short-acting medications allow for deliberate control of the anesthetic level in awake and asleep patients and with spontaneous and controlled ventilation (Tables 1 and 2).

Preoperative Preparation
Patients undergo a comprehensive and extensive preoperative interview the day before surgery with their anesthesia provider. This discussion is invaluable for evaluating and optimizing a patient’s emotional readiness for this unique surgical experience.10 The primary predictor of the success of awake craniotomy is prudent patient selection. Patients who are not candidates for awake craniotomy include patients with decreased mental capacity, a history of substance abuse, or a history of violent awakenings from anesthesia.11

On the day of surgery, baseline testing is performed using flash cards for picture and word identification. Benzodiazepine premedication is avoided because of its residual sedative and amnestic effects during the intraoperative assessment phase; however, the avoidance of benzodiazepines in this setting continues to be debated.10,12

A useful substitute for midazolam in an adult undergoing cortical mapping and tumor resection is a preoperative discussion in which good rapport and a trusting relationship are established between the patient and the anesthesia provider. If a patient remains tremendously anxious, a diminutive infusion of propofol may be titrated to effect en route to the operating room. Other preoperative pharmacological adjuncts consist of gastrointestinal premedication with aprepitant, metoclopramide, or famotidine. In addition, patients may receive antiepileptic prophylaxis levetiracetam or fosphenytoin.

Induction
On arrival in the operating room, patients are asked to make themselves comfortable on the operating room table in the surgical position, usually a lateral position.
Allowing patients to place themselves in the position required for the procedure optimizes patient comfort during the many hours they are awake and confined to the designated operative position. In addition to increasing comfort, self-positioning enables patients to recognize this position as a point of reference during emergence from the asleep phase of the anesthetic. The anesthesia team manages the patient’s airway from the side of the patient during the entire procedure.

Standard monitors are applied, with the addition of a bispectral index (BIS) monitor and an arterial line, which is usually inserted after induction. Hemodynamic monitoring is augmented with the use of a minimally invasive continuous cardiac output and stroke volume variation

<table>
<thead>
<tr>
<th>Drug</th>
<th>Mechanism of action</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propofol</td>
<td>GABA&lt;sub&gt;A&lt;/sub&gt; agonist</td>
<td>Rapid onset; antiemetic; antiepileptic; decreased intracranial pressure</td>
<td>Respiratory depression in combination with other narcotics</td>
<td>Intravenous anesthetic</td>
</tr>
<tr>
<td>Remifentanil</td>
<td>Selective µ-opioid agonist</td>
<td>Rapid offset; blunted hemodynamic responses</td>
<td>Bradycardia</td>
<td>Opioid</td>
</tr>
<tr>
<td>Dexmedetomidine</td>
<td>Selective α&lt;sub&gt;2&lt;/sub&gt;-agonist</td>
<td>Anxiolysis, analgesia; respirations maintained</td>
<td>Bradycardia; hypotension</td>
<td>Adrenergic receptor agonist</td>
</tr>
<tr>
<td>Fentanyl, avoid</td>
<td>Opioid agonist</td>
<td>Pain control</td>
<td>Prolongs wakeup; respiratory depression</td>
<td>Opioid</td>
</tr>
<tr>
<td>Midazolam, avoid</td>
<td>GABA&lt;sub&gt;A&lt;/sub&gt; agonist</td>
<td>Amnesia</td>
<td>Causes confusion during awakening</td>
<td>Benzodiazepine</td>
</tr>
</tbody>
</table>

Table 1. Anesthetics Agents Used in Awake Craniotomy
Abbreviation: GABA<sub>A</sub>, γ-aminobutyric acid ionotropic receptor family A.

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dose</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Induction medications</td>
<td>Maintenance (asleep)</td>
</tr>
<tr>
<td>Remifentanil</td>
<td>0.05-0.1 µg/kg/min</td>
<td>Short half-life</td>
<td>Bradycardia; caution with β-blockade</td>
</tr>
<tr>
<td>Propofol</td>
<td>1.0-2.0 mg/kg</td>
<td>Rapid onset of action; rapid change of level of sedation with dose; antiemetic effect; antiepileptic effect; decreased intracranial pressure</td>
<td></td>
</tr>
<tr>
<td>Rocuronium</td>
<td>50 mg IV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remifentanil</td>
<td>0.01-0.04 µg/kg/min</td>
<td>Pain control for extended time in same position</td>
<td></td>
</tr>
<tr>
<td>Propofol</td>
<td>50 µg/kg/min</td>
<td>Pain control</td>
<td></td>
</tr>
<tr>
<td>Desflurane</td>
<td>0.5 minimum alveolar concentration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ropivacaine 0.5% with 1:200,000 epinephrine</td>
<td>30-60 mL</td>
<td>Pain control</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Awake Craniotomy Drug Dose Chart
sensor. Two large-bore intravenous lines are adequate unless excessive blood loss is expected or the possibility of air embolism due to tumor location is anticipated. In either of these cases, central intravenous access is preferred.13

In female patients, indwelling urinary catheter placement is done in the supine position, and patients receive brief propofol sedation, which is then terminated for self-positioning. Urinary catheter placement in male patients occurs after induction of general anesthesia. Lidocaine jelly is used during insertion to lessen the discomfort of the catheter during the awake component of the surgery.

General anesthesia is induced using remifentanil and propofol. These medications are used for induction and maintenance of anesthesia because of their ability to provide smooth and rapid wake up of a cooperative patient. With the patient secured in the lateral position, one member of the anesthesia team maintains the mask fit while the other ventilates the patient. One dose of rocuronium (30-50 mg) may be given to facilitate full pharyngeal relaxation and LMA placement. The anesthesia provider inserts the LMA while facing the patient, who remains in the lateral position. This approach ensures the ability to manage the airway during the procedure should the patient become apneic or restless or his or her condition become unstable and full induction of general anesthesia and controlled ventilation be required. Administering a paralytic agent and managing the LMA and patient’s airway from the patient’s side reinforce the ability to do so and ventilate the patient for any reason should it become necessary.

Ventilation through the LMA must be satisfactory because it will facilitate brain relaxation and control of intracranial pressure. The ProSeal LMA (LMA North America, Inc, San Diego, California) is most often used because of its gastric access and high-pressure seal; however, use of the Supreme LMA (LMA North America, Inc, San Diego, California) offers an integral bite block.17,18 However, bupivacaine increases the risk of depressed cardiac contractility and conductivity.17 Thus, 0.5% ropivacaine, which has a pharmacological profile similar to that of bupivacaine, along with epinephrine, 5 µg/mL (1:200,000), in a total volume of 30 to 60 mL, is the common practice at the MD Anderson Cancer Center. In addition, before opening the dura, the surgeon can infiltrate the dura and temporalis muscle flap with an equal mixture of 1% lidocaine and 0.25% bupivacaine preservative-free local anesthetic. The scalp block consists of 7 main nerve blocks, as outlined in Table 3.

### Scalp Block

Patient comfort is paramount during the awake component of cortical mapping and tumor resection. Skull pins, which are inserted during surgical preparation, can be very stimulating.16 In addition to the occurrence of hypertension and tachycardia, stress hormones such as cortisol and adrenocorticotropic hormone are released in response to such noxious stimuli.17,18 Achievement of the surgical procedure, therefore, ultimately depends on a successful scalp block being performed by the anesthesia provider. In addition, local anesthetic infiltration of the temporal muscle flap and dura are performed by the neurosurgeon; these techniques offer hemodynamic and stress response control and enhance patient cooperation. During the postinduction period, a comprehensive, well-executed scalp block can prove to be the difference between a comfortable, compliant, awake patient and a patient requiring resedation.

Most studies recommend the use of 0.25% or 0.5% bupivacaine, with or without epinephrine, for a scalp block.17,18 However, bupivacaine increases the risk of depressed cardiac contractility and conductivity.17 Thus, 0.5% ropivacaine, which has a pharmacological profile similar to that of bupivacaine, along with epinephrine, 5 µg/mL (1:200,000), in a total volume of 30 to 60 mL, is the common practice at the MD Anderson Cancer Center. In addition, before opening the dura, the surgeon can infiltrate the dura and temporalis muscle flap with an equal mixture of 1% lidocaine and 0.25% bupivacaine preservative-free local anesthetic. The scalp block consists of 7 main nerve blocks, as outlined in Table 3.

### Intraoperative Wake Up

Once the dura is opened, the surgeon will ask the anesthesia team to awaken the patient for neurological evaluation and speech and/or motor testing. It is customary to have 2 anesthesia providers caring for the patient. While one is devoted to calmly reassuring and orienting the patient during the emergence phase, the other manages the patient’s blood pressure and heart rate and prepares for headache management and reinduction if general anesthesia becomes necessary. Nicardipine, labetalol, metoprolol, and esmolol should be available to control hypertension and tachycardia, and ephedrine and phenylephrine should be available to treat hypotension. Headaches are treated with lidocaine infusion or remifentanil at a low infusion rate. In addition, preoperative acetaminophen may prevent headaches.12 Ondansetron is administered before awakening the patient (typically before the bone flap is raised) to prevent nausea and vomiting. Propofol and dexamethasone, with their antiemetic properties, also help to reduce the occurrence of nausea and vomiting. Manninen and Contreras10 found that the frequency of nausea and vomiting in the early postoperative period is significantly lower in patients awake during craniotomy than in patients undergoing general anesthesia.

Monitoring with the BIS score may be used as an adjunct for timing the safe removal of the LMA and creating a smooth transition from anesthesia.19 A BIS value of 40 to 60 is a reliable indicator of adequate depth
<table>
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<tr>
<th>Nerves</th>
<th>Nerve branch</th>
<th>Sensory innervation</th>
<th>Steps and landmarks</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supraorbital nerve</td>
<td>Trigeminal nerve (V1 distribution, ophthalmic division into frontal nerve)</td>
<td>Forehead; anterior part of scalp; top of head</td>
<td>Palpate supraorbital notch; insert needle at the upper orbital margin perpendicularly (1 cm medial to supraorbital foramen); start at the supraorbital notch; ropivacaine 0.5%, 1-3 mL&lt;sup&gt;a&lt;/sup&gt;</td>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Supratrochlear nerve</td>
<td>Trigeminal nerve (V1 distribution, ophthalmic division into frontal nerve)</td>
<td>Forehead; anterior part of scalp</td>
<td>Medial expansion of the supraorbital block; 1 finger breadth medial to supraorbital nerve block; stay above the eyebrow line; ropivacaine 0.5%, 1-3 mL&lt;sup&gt;b&lt;/sup&gt; (medial)</td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Zygomatico-temporal nerve</td>
<td>Trigeminal nerve (V2 distribution, maxillary nerve)</td>
<td>Temporal, face to zygomatic region</td>
<td>1 cm lateral and 1 cm superior to lateral canthus of the eye above the zygomatic arch; inject incrementally (while withdrawing needle through temporalis muscle); deep and superficial infiltration from the posterior portion of zygomatic arch to the supraorbital margin; nerve arises between supraorbital and auriculotemporal nerves; ropivacaine 0.5%, 3-5 mL&lt;sup&gt;b&lt;/sup&gt;</td>
<td><img src="image3.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Auriculotemporal nerve</td>
<td>Trigeminal nerve (V3 distribution, mandibular nerve)</td>
<td>Temporal, lower lip, lower face, auricle, and scalp anterior-superior to auricle</td>
<td>At the tragus, 1-1.5 cm anterior to the auricle, palpate the superficial temporal artery (in temporal region at pinna superior to the temporomandibular joint); ear should move posteriorly as injection occurs; ropivacaine 0.5%, 1-3 mL&lt;sup&gt;b&lt;/sup&gt;</td>
<td><img src="image4.jpg" alt="Image" /></td>
</tr>
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**Table 3. Scalp Block Technique**
(From Osborn and Sebeo J.)

<sup>a</sup> Local anesthetic mixture: 0.5% ropivacaine with epinephrine, 5 µg/mL (1:200,000) in a total volume of 30-60 mL.

(Illustrations by David Aten, MA, CMI, senior medical illustrator, MD Anderson Cancer Center, Houston, Texas.)

continues on page 66
### Table 3. Scalp Block Technique
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<tr>
<td>Greater occipital nerve</td>
<td>Posterior ramus of second cranial nerve root (cervical plexus, C2-3)</td>
<td>Posterior part of scalp and occipital area</td>
<td>Palpate occipital artery; inject medial to artery between mastoid process and occipital protuberance and mark before induction; 2.5 cm lateral to nuchal median line (ensure negative blood aspiration); then inject ropivacaine 0.5%, 3-5 mL</td>
<td></td>
</tr>
<tr>
<td>Lesser occipital nerve</td>
<td>Ventral rami of C2 and C3 of spinal nerves</td>
<td>Posterior part of scalp</td>
<td>Field block behind ear and occipital area; create a &quot;wall&quot; of local or field block from posterior ear area to greater occipital nerve; infiltrate 2.5 cm lateral to greater occipital nerve, along the superior nuchal line; ropivacaine 0.5%, 3-5 mL</td>
<td></td>
</tr>
<tr>
<td>Greater auricular nerve</td>
<td>Cervical plexus of C2 and C3</td>
<td>Mastoid process; posterior auricular</td>
<td>Inject at the level of the tragus, 1.5 cm posterior to the ear; ropivacaine 0.5%, 3-5 mL</td>
<td></td>
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Local anesthetic mixture: 0.5% ropivacaine with epinephrine, 5 µg/mL (1:200,000) in a total volume of 30-60 mL.
(Illustrations by David Aten, MA, CMI, senior medical illustrator, MD Anderson Cancer Center, Houston, Texas.)
of anesthesia for incision through the dural opening of the brain. At a BIS value greater than 80, return to spontaneous respiration generally occurs and LMA removal quickly follows. On removal of the LMA, oxygen delivery is initiated via a nasal cannula inserted during the initial LMA insertion. Approximately 10 to 20 minutes are required for a patient to wake up once intravenous and inhalational anesthetics are discontinued. An awake patient is given time to restore alertness to the preoperative level. It is important to see familiar faces of the anesthesia team during this time. A calm, familiar voice helps keep agitation and confusion to a minimum. Discomfort from the skull pins, intracranial vascular retraction, prolonged positioning may necessitate the administration of small amounts of opiates.

Many complications are possible during the time from the asleep to the awake phase of the procedure. Lightening of anesthesia during the wake-up phase increases the metabolic rate and cerebral blood flow, and this change increases cerebral volume, which can compromise the surgical field by creating brain “tightness.” In addition, it is crucial to avoid the Valsalva maneuver, coughing, and vomiting, which can cause bulging of the brain. Small amounts of ice chips can help with dry mouth and decrease the need to cough.

Cortical Mapping

If speech centers are involved, picture cards that were evaluated for accuracy preoperatively are reviewed before cortical mapping to ensure that these centers have not been breached during exposure. If motor mapping of the extremities is needed, the patient must demonstrate movement of the affected extremity before cortical mapping takes place. The Ojemann neurostimulator (Radionics, Inc, Chicago, Illinois), with 5-mm spacing between the electrodes, is used. For localization of the primary language and motor cortex, the stimulator is applied in increments of 1 mA. A cortical area is considered eloquent if a motor response or twitch is generated or language errors or pauses are noted in multiple trials. Cortical mapping may last from 15 minutes to, in rare cases, 3 hours or more.

Constant communication can be tiresome to patients and anesthesia providers. This is yet another reason why it is imperative to build an excellent rapport with the patient preoperatively, as it facilitates communication intraoperatively. Often, a patient’s family member in the waiting room is called on a speakerphone to give the patient a break from the steady stream of flashcards. This approach helps to renew patient focus and provides additional support.

Cortical mapping can induce seizures. Although most seizures are focal, they have the potential to advance rapidly into general seizures. The reported intraoperative seizure incidence varies from 0% to 32%. If seizures are encountered, they are treated with ice saline irrigation to the brain until the seizures cease. Most seizures, whether focal or general, terminate spontaneously or are terminated by the ice saline irrigation; however, occasionally, seizures continue and become generalized tonic-clonic seizures that necessitate the administration of antiepileptic drugs followed by resedation with propofol and LMA insertion.

When the resection is complete, general anesthesia may be induced and an LMA reinserted. Hemostasis and dural, bone flap, and scalp closure are performed under general anesthesia. Propofol and remifentanil infusions are restarted, with the possible addition of a dexmedetomidine infusion for patients who are resedated only via total intravenous anesthesia.

Once the procedure is complete, the patient is awakened and taken to an overnight postoperative anesthesia care unit or to the intensive care unit, depending on comorbidities, surgical length, and outcomes.

The Future of Awake Craniotomy

Research has indicated that aggressive resection of certain brain tumors can lengthen survival. When these tumors arise near eloquent areas of the brain, the only way to confirm the sparing of these highly functional areas is to have the patient awake and participating during mapping of the brain. Although there are many promising functional brain mapping techniques that are being refined, such as functional magnetic resonance imaging, positron emission tomography scanning, magnetoencephalography, intrinsic optical signals, and transcranial magnetic stimulation, awake cortical mapping continues to definitively reveal the locations of language and motor centers specific to each patient.

REFERENCES


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**ACKNOWLEDGMENTS**

We thank the following staff at UT MD Anderson Cancer Center for their contributions to the course: Sarah Goss, CRNA, MSN, nurse anesthesia clinician; David Z. Ferson, MD, faculty-professor; Charles E. Cowles Jr, MD, faculty-assistant professor; Anh-Thuy Nguyen, MD, faculty-associate professor; Dave Aten, MA, CMI, senior medical illustrator; Dawn Chalaire, BA, scientific editor, Department of Scientific Publications.