

Practical guidance for monitored anesthesia care during awake craniotomy

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Monitored anesthesia care is a feasible option for anesthetic management during awake craniotomy. Patients selected for surgery are thoroughly evaluated by anesthesiologists, primarily focusing on their risk for airway emergencies, such as respiratory depression and obstruction, throughout the procedure. For patients with relative contraindications, a tailored approach is used to assess their suitability. Neuropsychiatric counseling is also helpful for enhancing the patient's ability to participate in and perform the necessary tasks during brain mapping. Building good rapport with the patient is essential for the success of awake craniotomy, as it helps foster trust and cooperation. Analgesia during awake craniotomy is primarily achieved through scalp nerve blocks or infiltration. Among the six scalp nerve blocks, I have described the zygomatic nerve block in detail. Proper positioning is crucial for both the surgical approach and the safety and comfort of the patient. Even when local anesthetics are effectively administered, many patients may still experience mild to moderate pain during the procedure. This pain is common and transient, typically occurring around the temporal region. In some cases, sedatives or additional analgesics may be necessary. Serious adverse events can arise, including those that require urgent life-saving interventions or those that interfere with brain mapping and the patient's ability to perform tasks. However, MAC in awake craniotomy offers the potential for an improved quality of life for individuals with brain tumors or epileptic seizures, as well as for those with disabilities, such as the deaf or visually impaired, in the future.

Keywords: Adverse events; Awake craniotomy; Dexmedetomidine; Monitored anesthesia care; Propofol; Remimazolam.

INTRODUCTION

Monitored anesthesia care (MAC) is a viable anesthetic management option for any surgery as long as the patient's spontaneous breathing is maintained. However, with regard to craniotomy, patients and their families are likely to experience significant anxiety and stress, as the patient will undergo a frightening surgery in an unfamiliar environment. Craniotomy can be performed while the patient is

awake and able to perform speaking or movement tasks in response to commands during a certain period of the surgery and is positioned immobilized with their head fixed. For the rest of the surgery, the patient remains in a state of minimal-to-moderate sedation. Patients may become anxious about awake craniotomy. MAC refers to the anesthetic care for awake craniotomies. This is challenging not only for patients but also for the medical staff involved, as maintaining a balance between safe sedation and consciousness

requires careful monitoring and adjustment throughout the procedure.

Awake craniotomy offers several advantages in terms of surgical outcomes and medical economics compared with craniotomy performed under general anesthesia and is widely practiced globally. Successful awake craniotomy can be achieved through a well-designed institutional strategy or protocol that includes proper training for medical staff and clear communication with patients and among all staff involved.

In 2020, my colleagues [1] published an article on a similar topic in the journal of *Anesthesia & Pain Medicine*. Therefore, instead of repeating the content, this study focuses on practical considerations based on recent literature and our institution's experience in which all the awake craniotomies are performed under MAC. I hope that this article will be helpful to anesthesiologists interested in awake craniotomy or those lacking experience with it.

CLARIFICATION OF THE NOMENCLATURES AND THEIR ACRONYMS FOR ANESTHESIA TECHNIQUES FOR AWAKE CRANIOTOMY IS NEEDED

The awake craniotomy process can be divided into three phases: pre-awake, awake, and post-awake [2]. During the pre- and post-awake phases, various levels of sedation, ranging from alert to general anesthesia, can be applied. Therefore, anesthesia techniques during these phases can be sequentially combined and adapted in various ways, depending on the circumstances.

In 1999, the American Society of Anesthesiologists defined general anesthesia and the spectrum of sedation, and classified sedation into three stages: minimal sedation,

moderate sedation (conscious sedation), and deep sedation (Table 1). In contrast to MAC, in the asleep-awake-asleep technique (SAS), asleep is relevant to deep sedation or general anesthesia. Additionally, confusion regarding acronyms derived from the first letters of asleep and awake exists in the literatures [3-5]. For example, AAA may refer to either the asleep-awake-asleep or awake-awake-awake technique, and AA may refer to either the asleep-awake or awake-awake technique. Additionally, the awake-asleep-awake sequence may be called either AAA or SAS, while asleep-awake sequences can be referred to as AA or SA.

In this review, I will use the acronym SAS to refer to the asleep-awake-asleep technique, in comparison to MAC referring to monitored anesthesia care, which is also known as conscious sedation or analgosedation.

SELECTED PATIENTS FROM THE SURGICAL PERSPECTIVE ARE EVALUATED FOR MAC OR SAS THOROUGHLY ACCORDING TO ANESTHESIOLOGISTS' PERSPECTIVE

An absolute contraindication for awake craniotomy is the patient's refusal or inability to communicate and cooperate, even with all possible assistance, regardless of the anesthetic approach used (MAC or SAS). Patients indicated for awake craniotomy undergo a detailed evaluation by an anesthesiologist. Unlike the MAC in other surgeries, the MAC during awake craniotomy requires special considerations. Anesthesiologists must evaluate patients primarily based on their potential for life-threatening situations, such as respiratory depression and airway obstruction. Patients with a difficult airway, chronic cough, obstructive sleep apnea, obesity, short neck, extreme age (very young or very old), severe cognitive deficits, severe anxiety disorders, or lower back pain

Table 1. Definition of General Anesthesia and the Spectrum of Sedation by the American Society of Anesthesiologists (Original Approval: October 13, 1999)

	Minimal Sedation Anxiolysis	Moderate Sedation/ Analgesia ("Conscious Sedation")	Deep Sedation/Analgesia	General Anesthesia
Responsiveness	Normal response to verbal stimulation	Purposeful response to verbal or tactile stimulation	Purposeful response following repeated or painful stimulation	Unarousable even with painful stimulus
Airway	Unaffected	No intervention required	Intervention may be required	Intervention often required
Spontaneous Ventilation	Unaffected	Adequate	May be inadequate	Frequently inadequate
Cardiovascular Function	Unaffected	Usually maintained	Usually maintained	May be impaired

are currently considered to have relative contraindications. However, these patients can be selected using a tailored approach. Neuropsychiatric counseling is also helpful in enhancing their ability to participate in and perform the requested tasks during the brain mapping process.

Young female patients tend to be more anxious about general anesthesia than older male patients [6,7]. However, age- and sex-related differences in anxiety and depression may not always apply to awake craniotomies. Although there was no statistical significance, a study on the patient's perspective of MAC [8] found that more male patients experienced stress than female patients (74.2% vs. 54.5%). To date, no research has been published on the differences in emergence behavior patterns as the primary endpoint between males and females during emergence from the pre-awake phase. Emergence agitation from general anesthesia is more common in mature male patients than in female patients [9]. Some young male patients who display a bluffing tendency often respond hyperactively during indwelling of peripheral intravascular catheter or urethral catheter insertion, or show restlessness or agitation during emergence from sedation. A preoperative scoring system using five variables was recently proposed to help select appropriate patients [10], with a focus on the surgical rather than the anesthetic perspective.

GOOD PATIENT RAPPORT IS IMPORTANT FOR SUCCESSFUL AWAKE CRANIOTOMY

Many studies on patients' perspectives on awake craniotomy have revealed that preoperative anxiety, distress, and depression are overestimated [11,12], and the degrees of preoperative anxiety and distress are related to the intraoperative pain threshold [12]. These could be reduced through extensive preoperative preparation for structured interviews. Preoperative interviews with compassionate communication would promote the patient's perception of control and alleviate distress and empower patients during awake craniotomy [12-14]. As most patients receive information via the Internet, the correct information on awake surgery should be provided to them [15]. During the preoperative visit, anesthesiologists will explain how MAC is performed, the different methods of anesthetic care during the three distinct phases, the surgical procedure and its duration, the tasks the patient will be asked to perform, the types of discomfort or risks they may experience, and the operating room environment. They will also address any questions the patient may have. The patient is informed of the prolonged positioning

in a head-fixed state, discomfort related to urinary catheterization, and noise from craniectomy. It is worth considering that the most stressful experience for patients is not pain but prolonged immobility.

Patients undergoing repeat awake craniotomy reported significantly lower levels of anxiety and distress than those from their first surgery. Despite the increased risks associated with longer surgery times and potential complications such as infection leading to readmission, they remained positive about surgery [16]. As the world becomes increasingly interconnected, more foreign patients who do not speak the local language seek awake craniotomies. While having a translator can be helpful, it remains uncertain whether these patients receive sufficient information to establish strong rapport.

As another example of neurosurgery suitable for MAC, burr hole surgery [17] can be performed relatively safely under MAC in patients with severe comorbidities who are unable to tolerate endotracheal intubation or the administration of general anesthetics. Short and minimally invasive cranial procedures can be performed effectively using MAC. In my institution, for severely morbid patients in whom general anesthesia is burdensome, infiltration with 0.75% ropivacaine, along with a small amount of sedative, is performed with a semicircular shape around the incision line, with the open side facing the vertex.

Pre-medication is generally not required. Benzodiazepines were also not used, as they may impair neurocognitive function and potentially interfere with the quality of emergence from sedation, as well as the patient's performance during brain mapping. Glycopyrrolate can cause a dry mouth, which makes it difficult for patients to speak during brain mapping. Water-soaked gauze on the tongue provides comfort and reduces dryness, thereby improving the patient's overall experience during the procedure.

PATIENT CARE IN OPERATING THEATER

Standard patient monitoring, including electrocardiography (ECG), blood pressure, pulse oximetry, capnography, and temperature, should be performed. Noninvasive blood pressure measurement is replaced with invasive blood pressure monitoring, as intermittent inflation of the cuff may interfere with patient sedation. Intravascular access should be secured transparently and firmly on the ipsilateral side of the lesion, because motor mapping typically involves the movement of the arm, foot, and hand on the contralateral

side of the lesion. End-tidal carbon dioxide is monitored qualitatively, along with the administration of supplemental oxygen via nasal prongs. Depending on the manufacturer of the patient monitor, ECG may also provide the respiratory rate by detecting chest movements through the precordial lead. The bispectral index (BIS) for MAC during awake craniotomy is useful for monitoring the depth of sedation, particularly with propofol infusion. The operating room temperature is adjusted to ensure patient comfort. Low temperatures in the operating room can cause patients to feel cold and shiver, thereby increasing discomfort, anxiety, and distress. It is important to cover patients with warm air blankets when they enter the operating room. However, over time, patients may experience discomfort due to prolonged exposure to heat. Regarding urethral catheterization [8], most male patients experience severe discomfort during insertion but generally tolerate it afterward. Lubricating the catheter with lidocaine gel and administering brief sedation with a small dose of propofol or dexmedetomidine can alleviate discomfort during insertion.

THE MAINSTAY OF ANALGESIA DURING AWAKE CRANIOTOMY IS USE OF LOCAL ANESTHETICS

The person performing the scalp nerve block may depend on the institutional protocol. In our institution, anesthesiologists perform scalp nerve blocks and infiltrations at the pinning sites, whereas the surgeon performs the blocks along the incision site. The surgeon draws an imaginary incision line on the scalp, which is helpful in selecting the appropriate scalp nerves to be blocked. Before insertion of the needle into the scalp, a bolus of fentanyl (50–100 µg) helps the patient tolerate the blocks.

The hemispheric scalp is fully innervated by the supraorbital and supratrochlear nerves (branches of the trigeminal V1 nerve), the zygomaticotemporal and auriculotemporal nerves (branches of the trigeminal V2 nerve), and the greater and lesser occipital nerves (from the C2 and C3 nerves). Classic scalp block techniques have been well described in the literature [18,19]. The volume of the local anesthetic administered at each injection site varies from 2 to 5 ml. Most subcutaneous injections create a wheal of approximately 1 cm in length around the insertion site to provide effective nerve blockade.

The anatomical landmark of the supraorbital nerve is the supraorbital notch, which can be easily identified by touch.

The needle is inserted perpendicularly, and injected subcutaneously above the eyebrow at the notch. Once the supraorbital nerve is blocked, the needle is directed 2 cm medially above the eyebrow level. Subcutaneous injection at this location blocks the supratrochlear nerve. Injection while touching the orbital rim with one hand is recommended to avoid inadvertent eyeball puncturing.

The landmarks for auriculotemporal nerve block are the superficial temporal artery, zygomatic arch, and tragus. After identification of the superficial temporal artery, the needle is inserted lateral to the artery, delete this phrase, and 1 cm anterior to the tragus. It is important to inject the local anesthetic at a depth of approximately 0.5–1 cm from the skin surface to avoid blocking facial nerve.

For zygomaticotemporal nerve block, a study by Jeong et al. [20] provides valuable information regarding Asian patients. The zygomaticotemporal nerve pierces the deep temporalis fascia 10 mm posterior to the frontozygomatic suture and 22 mm above the upper margin of the zygomatic arch. After exiting the deep temporalis fascia, it gives off one to three branches at a mean distance of 7.5 mm from the point where the nerve pierced the deep temporalis fascia and 24.8 mm above the upper margin of the zygomatic arch. The branches course superiorly and posteriorly, below the subcutaneous tissue. Therefore, local anesthetics can be injected for the zygomaticotemporal nerve block at three levels: deep (near the periosteum) and superficial (both in the superficial fascia and subcutaneous tissue) above the zygomatic arch, because it courses within a relatively large space and branches out with a variation in number. Injection into the subcutaneous tissue can often be replaced by a subcutaneous ring block extending from the lateral edge of the eyebrow to the anterior tragus.

For the greater occipital nerve block, the needle is inserted medial to the occipital artery, approximately halfway along the line connecting the occipital protuberance and mastoid process, taking care to avoid intra-arterial injection.

The lesser occipital nerve block is performed at the midpoint between the greater occipital nerve and the mastoid process as landmarks along the superior nuchal line.

Recently, ultrasonography-guided scalp blocks have also been reported [21]. For infiltration of local anesthetics in MAC for redo awake craniotomy, the location of the bony defect should be identified using plain skull radiographs to avoid accidental intracerebral injection of local anesthetics, which could cause a transient generalized tonic-clonic seizure [22]. To safely insert the needle into the scalp, the fol-

lowing steps are recommended. First, review the patient's surgical history and locate any bony defects. Second, the locations of defects on the scalp are marked or outlined. Third, if the defect is near the needle insertion site, the needle is inserted at the lowest possible angle from the scalp. Evaluation of the scalp nerve block should be assessed as either all or nothing. Supplemental blocks are administered if needed prior to positioning.

The choice of local anesthetic regimen depends on the physician's preference, considering factors such as onset time, duration of action, and maximal dose allowed. A mixture of long-acting local anesthetics such as ropivacaine or levobupivacaine and short-acting local anesthetics such as lidocaine has been used safely and effectively when combined with a 1:200,000 concentration of epinephrine. With the above regimen, the peak plasma concentration is reached in 15 min, with 1.1–1.5 µg/ml for ropivacaine and 1.9 µg/ml for lidocaine being below their toxic levels (2.2 µg/ml and 6 µg/ml, respectively) [23,24].

At my institution, I added an additional 20 ml of 0.9% NS and 0.3 ml of epinephrine (1:1,000) to a mixture of 20 ml of 0.75% ropivacaine and 20 ml of 2% lidocaine to increase the total volume to 60 ml. With the exception of the zygomatic-otemporal nerve block, approximately 3–4 ml was used for each scalp nerve block. This regimen is generally sufficient for scalp nerve blocks in the hemisphere and at the pinning sites.

WHICH ANESTHETIC CARE TECHNIQUE IS BETTER FOR AWAKE CRANIOTOMY, MAC OR SAS?

To date, both techniques have been used safely and effectively during awake craniotomy without any significant differences in clinical variables and outcomes. The choice between MAC and SAS for awake craniotomy depends on the anesthesiologist's preference. A European survey on the anesthetic techniques for awake craniotomy showed that 56% of responders used SAS with laryngeal mask airway (LMA) and intravenous anesthetics, and 44% of responders used MAC. Interestingly, 90% of respondents used only one preferred protocol [25].

Two studies using meta-analysis conducted in 2016 [26] or 2022 [4] revealed a comparison of clinical outcomes between MAC and SAS (Table 2). However, the authors of both studies stated that readers should interpret their results cautiously, because some analyses were based on an article with high risk of bias.

POSITIONING

Patients undergoing awake craniotomy are usually positioned in a supine, semi-lateral or lateral position with their heads fixed. There are several important considerations regarding positioning. Sometimes, there may be a conflict between the anesthesiologist and surgeon regarding head and neck positioning. Surgeons may prefer the head and neck to be rotated and flexed away from the trunk for easier surgical access, whereas anesthesiologists prefer the head and neck

Table 2. Comparison of MAC and SAS from Two Meta-Analysis Studies

Article numbers, years published	Natalini et al. [4], 2022	Stevanovic et al. [24], 2016
	37 articles, 2014–2018	46 articles, 2007–2015
Findings		
Awake craniotomy failure rate	MAC favorable (1% vs. 4%), (MAC/SAS, OR = 0.28, 95% CI 0.11–0.7)	NS, 2% (of pooled data)
Conversion into general anesthesia rate	NA	MAC favorable. 2% (SAS/MAC, OR = 2.17, 95% CI 1.22–3.85)
Intraoperative seizure rate	SAS favorable (10% vs. 4%), (OR = 2.38, 95% CI 1.05–5.39)	NS, 8% (of pooled data)
Intraoperative nausea and vomiting rate	NS (4% vs. 8%)	NA
Duration of surgery	MAC favorable (224 min vs. 327 min) (95% CI 260–395 min)	NA
Hospital length of stay	MAC favorable but NS (3.96 d vs. 6.75 d) (95% CI 3.9–11.6 d)	NA

MAC: monitored anesthesia care, SAS: asleep-awake-asleep, OR: odds ratio, NA: not available, NS: not statistically significant.

to be in a less rotated sniffing position [2]. This is to ensure that the patients can open their mouths wide enough for LMA insertion.

Before finalizing the positioning, it is important to ask the patient if the position is comfortable rather than simply asking if they can tolerate any discomfort caused by the position. All the dependent parts of the body should be comfortably padded. Improper positioning is often linked to the failure of brain mapping or overall awake craniotomy.

SELECTION OF SEDATIVES AND OR ANALGESICS FOR MAC DURING AWAKE CRANIOTOMY

Although local anesthetics have been successfully administered, most patients still experience mild to moderate pain during the procedure [25,27].

The sources of pain during awake craniotomy usually stem from both the extracranial and intracranial regions as well as from the back and dependent body parts. The pain may be related to specific areas of the brain (such as the temporal, frontal, parietal, or insular lobes) and is typically transient in nature [18,28]. This pain can usually be managed effectively with analgesics such as 1% lidocaine injected into the dura, small doses of opioids like fentanyl or remifentanyl, or non-steroidal anti-inflammatory drugs [25]. If opioids are administered, the prophylactic use of dexamethasone [29] is recommended to reduce nausea and vomiting. When lidocaine is injected into the dura, it is necessary to ensure that the local anesthetic does not enter the intracranial space by sufficient irrigation with saline. Positive suggestions are helpful, as evidenced by the awake-awake technique for awake craniotomy [30,31]. Informing the patient in advance of potential pain during the procedure can help them tolerate it better. This is similar to watching a scary horror movie; if you are warned about an upcoming frightening scene, you are less likely to be afraid when it happens.

The ideal drugs for MAC during awake craniotomy [32] should allow for a fast and predictable onset and offset of action and easy control of sedation levels, and should not cause respiratory depression, hemodynamic instability, or trigger vomiting or seizures. Currently, propofol, dexmedetomidine, and remimazolam (with or without flumazenil) are used effectively and safely in MAC for awake craniotomy [33-36]. Most sedatives are discontinued when a dural incision is made.

Propofol and remifentanyl have long been the standard drugs for MAC during awake craniotomies. A low-dose propofol infusion (20–50 µg/kg/min) along with remifentanyl (0.01–0.06 µg/kg/min) can be used to achieve minimal or moderate sedation without causing airway obstruction. Many researchers have used propofol and remifentanyl with target-controlled infusion (TCI) in effect-site concentration-targeting mode [33]. Since the introduction of dexmedetomidine into clinical practice, its use seems to be increasing owing to its unique advantage of minimal risk of respiratory depression compared with that of propofol. However, whether dexmedetomidine is superior to other sedatives for MAC during awake craniotomy is controversial. Meta-analyses [32,37] showed that dexmedetomidine was comparable to propofol in terms of efficacy and safety for MAC during awake craniotomy. The surgeon was more satisfied with the circumstances of dexmedetomidine use [32]. However, there have been a few unfavorable results regarding the use of dexmedetomidine for MAC in awake craniotomy. The frequency of intraoperative seizures (22%) was higher in the dexmedetomidine group than in the propofol group (11%) [34]. In addition, poor quality of awakening [38] and delayed awakening [35] due to dexmedetomidine have also been reported. Unlike BIS values with propofol, the BIS values corresponding to the level of sedation with dexmedetomidine lack consistency [39].

In a prospective observational study conducted at a single center, a regimen combining a dexmedetomidine infusion (0.7–1 µg/kg/h) with remifentanyl administered via TCI (0.5–1 ng/ml using the Minto model) was found to be highly satisfactory for MAC during awake craniotomy [8].

Remimazolam, a novel ultrashort-acting benzodiazepine, in awake craniotomy has recently been reported [36,40]. The distinct advantage of remimazolam over propofol or dexmedetomidine is the antidote, flumazenil, which allows faster awakening than propofol (remimazolam, 21 min vs. propofol, 19 min vs. remimazolam with flumazenil, 15 min) [36]. Intermittent bolus injections of remimazolam are useful to alleviate prolonged discomfort or anxiety are useful [41]. However, remimazolam increases secretion and requires the use of a neuromuscular blocking agent for LMA insertion [42]. Serious adverse effects of remimazolam have also been reported after flumazenil administration, including anaphylaxis, delayed emergence, and resedation after flumazenil administration [43].

These drugs can be administered via bolus injections, continuous infusions, or TCI. For the use of TCI, when tar-

getting effect-site concentration, even a small increase in the effect-site concentration triggers an initial bolus injection to reach an unexpectedly higher plasma concentration, potentially leading to unanticipated respiratory depression or hemodynamic instability [44]. Therefore, targeting the plasma concentration is recommended to determine the effect-site concentration.

Our protocol involves only propofol infusion via TCI, targeting a plasma concentration of less than 3 µg/ml (usually around 2 µg/ml), and increasing to 4–5 µg/ml in cases of restlessness. For pain control, intermittent administration of fentanyl (less than 1–2 µg/kg) or paracetamol is used, similar to other protocols [25]. Patients will be able to state their names at an effect-site concentration of approximately 0.51–0.69 µg/ml [45].

EMERGENCE FROM SEDATED STATE AND PREPARATION FOR BRAIN MAPPING

The goal during this period is for the patient to remain in a cooperative, pain-free, and comfortable state. Therefore, patients' awakening is evaluated by their response to low-voiced verbal commands rather than tactile stimuli. Some water-soaked gauze in the mouth or slight postural adjustments can be allowed. The room temperature should be maintained at a comfortable level. The anesthesiologist, along with the surgical team staff involved in brain mapping, should continually communicate with the patient, who should not feel left alone during this period.

SERIOUS ADVERSE EVENTS MIGHT BE EXPECTED IN ADVANCE AND ARE OFTEN RELEVANT TO SURGICAL PROCESSES

All events that occurred were presented according to their frequency and resolution (Table 3). Serious adverse events during awake craniotomy can be grouped into two categories [4,10]. The first category includes events that may require urgent life-saving interventions, such as respiratory failure, hemodynamic instability, uncontrolled coughing, severe nausea and vomiting, and complications such as cerebral edema or hemorrhage. The second category includes events that affect brain mapping and task performance. However, the second category of events may lead to urgent life-saving interventions. Although serious adverse events are rare, managing a patient with a fixed head state is challenging. Therefore, it is crucial that all necessary emergency kits, including an independent suction device, are prepared nearby. If these events are not resolved, the head frame may need to be unfixed to secure the airway via endotracheal intubation or LMA insertion. In a cadaver positioned to simulate awake craniotomy conditions, LMA proved to be the fastest and most reliable primary method for securing the airway, achieving placement within 6 s. Fiberoptic bronchoscopy through an LMA and video laryngoscopy successfully secured the airway in 41 and 49 s, respectively. Oral and nasal fiberoptic approaches have been partly successful [46].

Aspiration of vomitus or uncontrolled coughing during awake craniotomy may cause the brain tissue to bulge. A history of asthma and remifentanyl use are both associated with an increased risk of severe respiratory events [47]. For

Table 3. Intraoperative Adverse Events and Subsequent Resolution during Awake Craniotomy

Intraoperative events	Gross incidence	Resolution	No resolution
		Rate (%)	Rate (%)
Delayed awakening	11.5%	100%	0%
Headache	14.6%	96.6%	0.5%
Iterative errors during performing tasks	1%	30.8%	2.3%
Nausea and vomiting	3.1%	100%	0%
Posture discomfort	2.1%	80%	0.5%
Epileptic seizures	2.3%	100%	0%
Increasing tiredness	0.2%	16.7%	1.3%
Sudden neurologic deterioration	1%	80%	0.3%
Hypertension	0.5%	66.7%	0.3%
Hypotension	0.2%	10%	0%

Content was taken from the study by Elia et al. [8].

patients with obstructive sleep apnea who were contraindicated to awake craniotomy in the past, a nasopharyngeal airway was successfully applied before or after head fixation [48]. It needs to be inserted smoothly with the aid of a lubricant and under warm, flexible conditions to avoid nasal bleeding. A high-flow nasal cannula can be used in these patients [49].

POOR QUALITY AND DELAYED COMMUNICATION CAN LIMIT BRAIN MAPPING AND EVEN THE EXTENT OF TUMOR RESECTION

During brain mapping and task performance, patients are asked to count, read, and name objects displayed in a notebook and to move their extremities, which is the so-called language mapping or motor mapping. Meanwhile, direct electrical stimulation, motor-evoked potentials, somatosensory-evoked potentials, and electrocorticography (ECoG) are applied to the relevant brain areas. Delayed awakening or somnolence from sedation can interfere with brain mapping and task performance. MAC using propofol allowed the patients to wake up within 19 min after the cessation of administration. However, approximately 10% of patients experienced somnolence, and one-quarter of these patients failed to complete the mapping, probably due to hyperactive movements such as restlessness or emergence agitation. Awakening time was positively correlated with the incidence of somnolence, and somnolent patients were able to participate in brain mapping within a median duration of 34 min [45]. It is unclear whether the quality of awakening is associated with the type of sedative used, as the BIS values during the pre-awake phase did not differ between patients with and without somnolence.

Intraoperative seizures during awake craniotomies are among the most distressing complications. Intraoperative seizures have been reported to occur at a frequency of 0–30% depending on the clinical context and diagnostic criteria used [4,34,50,51]. These criteria include clinically observed seizures, clinically observed but uncontrolled seizures, seizures detected only on an electroencephalogram or ECoG, and electrical stimulation-induced seizures. Ninety-three percent of intraoperative seizures during awake craniotomy under MAC were focal, and 69% triggered by direct electrical stimulation. Most seizures resolved spontaneously with cold saline irrigation or a small dose of propofol [51]. In the worst cases, general anesthesia may be required.

Several risk factors have been suggested to predict intraoperative seizures, including younger age, frontal lobe lesions, previous preoperative seizures, use of multiple antiepileptic drugs, low-grade gliomas, positive mapping, dexmedetomidine use, and MAC use. However, these factors remain controversial and have been reported to vary depending on the type of lesion (tumor vs. epilepsy), patient demographics (such as race), and research protocols. Therefore, anesthesiologists must anticipate and prepare for all potential intraoperative adverse events, considering their severity (mild vs. severe), duration (transient vs. prolonged), and ease of management.

CARE DURING POST-AWAKE PHASE

As soon as the neurosurgeon completes the intended brain mapping, which refers to the completion of defining the margins of the brain tumor, the patient can achieve a sufficient depth of sedation as long as spontaneous ventilation is maintained. At this stage, tumor removal may be in progress, complete, or yet to begin. In this post-awakening phase, a significant amount of time may have already passed, meaning that the patient may have required a substantially different level of sedation and analgesia compared to the pre-awakening phase. Either a partial combination or a suitable selection of propofol, dexmedetomidine, remifentanyl, and fentanyl can be used, as appropriate.

FUTURE PROSPECTS

I am confident that the challenges associated with MAC during awake craniotomy will continue to diminish as surgical techniques improve, neuroscience advances, and monitoring technologies become increasingly sophisticated. Recent brain mapping efforts await the development of monitoring techniques for higher-order cognitive functions, including visuospatial cognitive and social executive functions [52].

Over time, patients will also likely become more accustomed to awake craniotomies. I believe that the use of MAC in neurosurgery will gradually expand in the near future, driven by advancements in functional brain anatomy, artificial intelligence, and neural networks. Furthermore, MAC in neurosurgery has the potential to enhance the quality of life of individuals with disabilities such as deafness or visual impairment.

CONCLUSION

Monitored anesthesia care for awake craniotomy can be challenging for anesthesiologists. However, with vigilance and careful consideration, along with scalp nerve blocks or infiltration blocks, it can become a safe anesthetic method that benefits more patients.

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CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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