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Awake craniotomy: indications, benefits, and techniques

Craneotomía en el paciente despierto: Indicaciones, beneficios y técnicas

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Abstract

Awake craniotomy is mainly used for mapping and resection of lesions in vitally important brain areas where imaging is not sufficiently sensitive. These are most commonly speech and motor areas. The awake approach has become increasingly popular with wider indications due to the advantage of better neurological and other perioperative outcomes including analgesia and postoperative nausea and vomiting. Improvements in anesthetic agents and techniques especially laryngeal mask airway have made a great contribution. Frequently used medications are propofol, dexmedetomidine, and remifentanil. Common anesthetic regimens range from light-moderate sedation, deep sedation, or general anesthesia during the pre-mapping and postmapping phases. In all sedation-anesthesia techniques, the patients are awake and able to speak and/or move during the mapping phase. This approach to intracranial surgical procedures requires skill, experience, and commitment on the part of the entire OR team. This review, from the point of view of authors, discusses the indications and contraindications, benefits, anesthetic techniques, challenges, and management, as well as potential future directions of awake craniotomy.

Resumen

La craneotomía con el paciente despierto se utiliza fundamentalmente para el mapeo y la resección de lesiones en áreas de vital importancia en el cerebro, en donde las imágenes no son suficientemente sensibles. Se trata por lo general de las areas del habla y motoras. El abordaje con el paciente despierto ha adquirido cada vez más popularidad y se han ampliado sus indicaciones gracias a la ventaja de mejores desenlaces neurológicos y perioperatorios, entre ellos la analgesia y la náusea y vómito postoperatorios. Los avances en los agentes y las técnicas de anestesia, particularmente la mascarilla laríngea, han hecho grandes aportes. Los medicamentos de uso frecuente son propofol, dexmedetomidina y remifentanilo. Los esquemas anestésicos comunes van desde la sedación leve a moderada, sedación profunda, o anestesia general durante las fases pre y post-mapeo. En todas las técnicas de sedación - anestesia, los pacientes se encuentran despiertos y con capacidad para hablar y/o moverse durante la fase de mapeo. Este abordaje al procedimiento quirurgico intracraneal requiere pericia, experiencia y compromiso por parte de todo el equipo de la sala de cirugía. Esta revisión hace referencia a las indicaciones y contraindicaciones, beneficios,

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Table 1. Contraindication to awake craniotomy

Contraindications	Reasons	
Absolute contraindications	Patient refusal	
Relative contraindications	Neurological	Dysphasia, confusion, somnolence, cognitive disorders (dementia, Down's syndrome), unable to remain still for long periods[6]
	Psychiatric	Claustrophobia, mood instability
	Airway	Uncontrolled coughing, morbid obesity, obstructive sleep apnea
	Tumor characteristics	Large and highly vascular tumors, middle fossa floor lesion (uncomfortable position ± dural pain)[10]

Source: Compiled by the authors based on personal experience and the literature.

técnicas de anestesia, desafíos y manejo, así como a posibles orientaciones a futuro de la craneotomía con el paciente despierto.

Introduction

Awake craniotomy can be defined as an intracranial surgical procedure where the patient is deliberately awake for a portion of the surgery, usually for mapping and resection of the lesion. It has a long history that pre-dates general anesthesia (GA) as there are many examples of paintings and descriptions of such procedures, especially trephination, dating back over a thousand years. During the last several decades, this procedure has become increasingly popular with wider indications prompted by accumulating evidence that patients receiving awake craniotomy have better outcomes in many aspects. The improvements in anesthetic agents and techniques, especially shorter and more dependable durations of actions, have also made a great contribution. Some aspects of awake craniotomy, including indications and contraindications, benefits, anesthetic techniques, challenges, and potential future directions are discussed. Minimally invasive procedures done through a burr hole, for example, placement of deep brain electrodes for Parkinson's Disease, are also technically awake craniotomies, but they are not discussed in this review.[1,2]

Indications

Awake craniotomy is used for any intra-axial mass lesion residing adjacent to or in eloquent brain based on pre-operative imaging, including motor, and language cortex, and also cortex responsible for other functions, for example, frontal lobe-executive functions. The lesions are primarily gliomas, cortical, and subcortical, both high and low-grade, as the survival rate is related to the extent of resection.[3] Intraoperative stimulation mapping in an awake patient can also be used in (1) refractory epilepsy, as extratemporal seizure foci are often close to eloquent brain areas[4]; (2) vascular lesions (e.g., arteriovenous malformation) near eloquent areas.[5]

Contraindications

Absolute and relative contraindications are shown in Table 1. There are also some debated contraindications, such as serious medical conditions (congestive heart failure, when ejection fraction $<10\%$),[6] 3rd trimester pregnancy with looming neurological crisis,[7] and patient's age (the reported age range is 9–90 years old).[8] Awake brain tumor surgery can be performed safely by experienced teams with low complication rates. This is regardless of tumor site, size, and pathology; body mass index; smoking status; American Society of Anesthesiology classification; seizure duration and frequency; emotional or psychiatric history.[9]

Benefits

The goal of awake craniotomy is to maximize tumor resection while preserving neurological function. This is achieved by stimulation mapping intraoperatively in an awake patient. With language and sensorimotor mapping functional aspects of the brain can be more accurately delineated so that patients can have more extensive tumor resection, reduced need for postoperative intensive care monitoring and less cost,[11,12] fewer neurological deficits (7% vs 23%), shorter hospital stay (1.7 vs 9 days),[13] longer survival. In addition, after awake craniotomy, patients need less intraoperative vasopressor, have less pain and less narcotic usage, and reduced postoperative nausea and vomiting. Although this procedure can be stressful with up to 30% of the patients having considerable pain and 10% to 14% experiencing significant anxiety, patient acceptance and postoperative satisfaction are high.[14] Posttraumatic stress disorder does not seem to occur.[15] As awake craniotomy with light-moderate sedation doesn't require mechanical ventilation, it avoids physiological disturbance associated with GA. A detailed

Table 2. Challenges of light-moderate sedation during pre-awake phase

Problems	Causes	Solutions
Agitation	Long operations	Comfort, encouragement and empathy
	Inadequate sedation	Increase sedative medication
	Inappropriate sedation choice	Reduce sedation so that patient is more aware of surrounding, reduce or discontinue propofol and use Dexmedetomidine
	Inadequate analgesia	Increase analgesia medication, surgeon adds more LA
Airway compromise (desaturation, hypercapnia)	Excess propofol without airway protection[21]	Alert surgeons, call for help, stop all infusions, mask ventilation with jaw thrust, oral/nasal airway, bilateral nasopharyngeal airways,[22] BiPAP, LMA, ETT. Succinylcholine if chest rigid, small dose (10 mg) succinylcholine if severe laryngospasm

BiPAP = bilevel positive airway pressure; ETT = endotracheal tube; LA = local anesthetic; LMA = laryngeal mask airway.
Source: Compiled by the authors based on personal experience and the literature.

discussion of the potential disadvantages of GA has recently been reviewed.[16] The data suggest awake craniotomy could improve access to neurosurgical care in poorer countries.[17]

Anesthetic techniques

Awake craniotomy requires skill, experience, and the commitment of the entire OR team.

Pre-operative patient interview by all team members is essential in building trust and engagement. A common cause of failure is poor patient communication intraoperatively. Surgeons, anesthesiologist, and nurse provide patients with reassurance and empathy, mitigating their anxiety. Patients should be informed of constant intraoperative face-to-face interactions, and other details including positioning, insertion of an indwelling urinary catheter, craniotomy noise, and mapping-related tasks. Pre-operative assessment of language function needs to be done.

Pre-medication

Pre-medication should be personalized according to the patient's condition and needs. In general, some medications should be avoided or used cautiously, such as midazolam, atropine, and scopolamine, as they can impair neurocognitive function and lead to confusion or delirium. However, a small dose of midazolam (1–2-mg intravenous [IV]) is beneficial in highly anxious younger patients with normal pre-operative neurologic function. Patients having seizure mapping should not receive any medications that suppress epileptiform activity, for example, midazolam, anti-convulsants. There is no consensus on the need to administer anti-convulsants in patients with no prior seizures.

Monitoring

Standard monitoring including electrocardiogram, oximetry, non-invasive and intra-arterial blood pressure, end tidal carbon dioxide, respiratory rate, and urine output is used. Monitors should be placed on the same side as brain lesion to avoid interfering with contralateral sensorimotor monitoring. Processed electroencephalogram (e.g., BIS [Medtronic Inc, Houston, TX, USA], SedLine [Masimo Corporation, Irvine, CA, USA]) monitoring may help shortening the patient awakening time.[18]

Positioning

Patients usually are lateral or semi-lateral, turned 90 degrees in reference to the anesthesia workstation and facing the anesthesia team to allow face-to-face interaction and airway management. The head is usually secured in a head frame.

Anesthetics

Currently, several techniques are used in clinical practice, mainly divided into 2 groups: (1) Asleep–awake–asleep. The patient will have GA with laryngeal mask airway/endotracheal tube (LMA/ETT) for the craniotomy and closure but awakened and extubated for mapping and resection. (2) Awake–awake–awake. The patient will be awake with sedation (light, moderate, or deep) with spontaneous ventilation for the craniotomy and closure. With both approaches, no medications are usually administered during the mapping phase. The choice of technique must take into account team preference, tumor location, neurological status, body size, age, motivation, and medical comorbidity in addition to the patient's physical condition.

Choice of medications varies interinstitutionally and among individual teams. To achieve smooth transitions and facilitate intraoperative mapping, anesthetics need to have rapid onset and offset, titratability, and minimal lingering effects. The most commonly used agents are propofol, fentanyl, remifentanil, and dexmedetomidine (DEX), sevoflurane is also used in some institutes. DEX has the unique advantage in that it causes only slight respiratory depression but provides some sedation and analgesia and can be used in combination with other agents or as a sole sedative.[19] Unlike propofol and midazolam, it does not augment neurologic dysfunction.[20]

Pre-awake phase

Local anesthesia, either local infiltration and/or scalp blockade, provides effective pain control for both awake craniotomy and GA, and reduces usage of IV opioids. Commonly scalp nerve blockade and local infiltration along the incision line are used with a combination of lidocaine, longer acting agent (bupivacaine or ropivacaine), and epinephrine. Usually there is no pain when dura is manipulated; however, irritations of nerves innervating dura in close proximity to meningeal vessels can cause pain. This is usually managed with infiltration of local anesthetic (LA) along the meningeal vessels.

Commonly used anesthetic regimens for awake craniotomy

1) Light-moderate sedation: Low-dose propofol (20–50 μg/kg/minute or 0.5–2.0 μg/mL) and remifentanil (0.01–0.06 μg/kg/minute or 0.2–1.5 ng/mL) infusions should be titrated to make the patient drowsy but arousable, without airway obstruction. DEX 0.3 to 0.5 μg/kg/hour can be used when propofol and remifentanil are not satisfactory or hypoventilation and airway obstruction require propofol and/or remifentanil to be reduced or stopped. Some patients become very disinhibited with propofol and DEX should be added or completely replace the propofol.
2) Deep sedation: The aim is to maintain spontaneous ventilation but with the use of an airway device for airway patency, for example, nasal trumpet(s) or LMA.

Challenges encountered with sedation are shown in Table 2.

Anesthetic regimens for GA. Intravenous infusions (propofol 50–100 μg/kg/minute or 1.5–4.0 μg/mL; remifentanil 0.1–0.2 μg/kg/minute or 2–4 ng/mL), or the use of inhalational agents (sevoflurane or desflurane $<$0.5 minimum alveolar concentration [MAC]) along with remifentanil 0.1 to 0.2 μg/kg/minute or 2 to 4 ng/mL, can effect a rapid and smooth transition from asleep to awake. Endotracheal intubation, either orally or nasally, has been used in the past. However, the transition from asleep to awake can be very challenging because of coughing and agitation. Currently, a more popular choice is an LMA, which produces less stimulation and a smoother transition.[23]

Awake phase. The goal is to transition smoothly and rapidly without agitation, confusion, or drowsiness from sedation or anesthesia to an awake patient. The patient needs to be engaged, cooperative, pain-free, and comfortable for mapping and tumor resection. All agents are stopped, although it is sometimes useful to keep a very low dose of remifentanil (0.01–0.05 μg/kg/minute or 0.2–1 ng/mL) running or administering small doses of fentanyl for analgesia. Pain should be managed with supplemental LA and possibly IV acetaminophen. Non-pharmacological intraoperative management should be used to reduce fear and anxiety.[24] Empathy, hand-holding, reassurance, ongoing encouragement, coaching, and conversation are all useful and important. A sponge soaked with ice-cold water can be used to wet the patient's lips and mouth for comfort. The patient can be allowed to move limbs and hips at appropriate times. An air blanket is used to provide either warm or cool air to maintain a comfortable temperature.

Physiological test

Motor and sensory pathways. Awake surgery provides accurate mapping of both superficial and deep pathways of the limbs, face, and mouth. Mapping can elicit or inhibit movements. Responses of orofacial musculature, laryngeal activity, and vocalizations can be recorded as tingling or movement, for example, withdrawal of protruded tongue, or speech arrest.[25] Similarly, tingling, twitching, or movement in the limbs may be elicited, most commonly arms and hand. The anesthesiologist should observe the patient carefully and report every movement to the surgeon, and the patient should also be instructed to report any abnormal movement or sensation. The stimulation mapping allows not only delineation of the cortical areas but also allows the surgeon to stimulate and monitor subcortical tracts.

Language. Speech areas cannot be safely localized on the basis of anatomical landmarks. To assess speech, the Visual Object Naming Test is frequently used. The Boston Naming Test consists of 60 drawings of common objects graded in difficulty, for example, window, car, dog, guitar. In addition, language functions can be studied with greater refinement and complexity.[26] Bilingual patients need to be tested in both languages as the anatomical areas may not entirely overlap.

Visual. Intraoperative brain mapping of cortical visual cortex with subcortical mapping of visual tracts may be useful to minimize risk of permanent hemianopia in tumors located in the parieto-occipital area. Identification of optic radiations by direct subcortical electrostimulation is a dependable method to reduce permanent injury in surgery for gliomas involving visual pathways.[27] Methods to identify other functions such as memory and counting are of interest and being developed.[28]

Challenges during the awake phase. Common challenges include hypertension, seizures, somnolence, agitation, oxygen desaturation, tight brain, and shivering.[29]

(1) Hypertension: This is most commonly secondary to pain, agitation, and anxiety. However, other causes should also be sought such as hypoxia, hypercapnia, and DEX associated. Treatment should focus on managing the cause. Labetalol or esmolol may sometimes be necessary.
(2) Seizures: Seizure incidence is 3% to 16% and happens during cortical and subcortical stimulation mapping. The incidence is less if the surgeon avoids stimulating an area twice in rapid succession. Continuous monitoring of electrocorticography for spikes or sharp waves within 5 seconds after each stimulation allows early detection. Patients with a history of seizure and younger patients especially with tumors of the frontal lobe are more prone to seizures.[19] Intraoperative seizures have a higher incidence of transient motor deterioration and longer hospitals stay.[30,31] First-line treatment of stimulation-evoked seizures is irrigation of the cortex with cold crystalloid solution, and this can be repeated as often as necessary. Intravenous propofol, in small (30–50 mg) repeated doses, is effective, but one must be cautious so as not to produce medication-induced coma resulting in airway compromise. IV fosphenytoin, valproate, lorazepam, or a barbiturate may rarely be needed acutely. Most resolve without adverse outcomes. Cardiac arrest and apnea may occur. Urgent intubation and conversion to GA is necessary for prolonged seizures >5 min.
(3) Emergence agitation and delirium may occur if the pre-awake phase is with GA or deep sedation. Contributing factors include older age; pain; disorientation; inappropriate use of naloxone, flumazenil, neostigmine, and atropine; oxygen desaturation; hypercapnia; urethral stimulation; and bladder distention. It can be very difficult to manage, and there is no consensus on the best approach. An approach is to reinduce anesthesia with a propofol bolus (30–50 mg), then administer a DEX bolus 0.1 to 0.2 μg/kg before the 2nd wake-up attempt. Low-dose remifentanil infusion 0.01 to 0.05 μ g/kg/minute or 0.2 to 1 ng/mL, droperidol or haloperidol before reawaking and physostigmine bolus 0.5 to 1.0 mg are all suggested strategies.
(4) Somnolence: This usually reflects residual anesthetic effects or from anti-convulsants. The best strategy is prevention by early termination of DEX and propofol, and the avoidance of large doses of midazolam or longer acting opioids.
(5) Nausea and vomiting: These are most commonly associated with opioids; other common associated factors are age, gender, and anxiety. The incidence is much lower with the common use of propofol. Management includes empathy, ondansetron, and small dose of propofol (20–30 mg).
(6) Hypothermia and shivering: These should be prevented by the use of blankets, warm air devices, and appropriate room temperature. Tramadol 50 mg or 25 to 30-mg meperidine may be effective.

Postawake. Similar to the pre-awake phase, one can also choose awake, spontaneous ventilation under light or deep sedation, or GA with airway control. Sedation often suffices. The patient usually requires lower rates of sedative infusions during the postawake phase than during the pre-awake phase as patients are often fatigued, and there is a lower level of painful stimuli during skull closure.

Postoperative care. The patient should initially be cared for in a high dependency unit or ICU familiar with neurosurgical patients. Pain management can be achieved by small doses of opioids intravenously including with patient controlled analgesia, oral opioids combined with acetaminophen.[32]

Future research

High-quality randomized clinical trials relevant to the role of anesthesia in the outcome after awake brain tumor resection is lacking. Outcome-oriented studies comparing GA versus MAC and the impact of specific anesthetic agents on brain tumor outcomes (tumor recurrence and progression, survival rate) are needed. Despite many studies comparing short-term outcomes with different anesthetics and analgesics, there is a need for large randomized controlled clinical trials that examine long-term outcomes including tumor recurrence, survival, and quality of life.[33–35]

Ethical disclosures

Protection of human and animal subjects. The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics commit-tee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent. The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author is in possession of this document.

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Conflict of interest

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References

1. Hansen E, Seemann M, Zech N, et al. Awake craniotomies without any sedation: the awake-awake-awake technique. Acta Neurochir 2013;155:1417–1424.
2. Sajonz BE, Amtage F, Reinacher PC, et al. Deep brain stimulation for tremor tractographic versus traditional (DISTINCT): study protocol of a randomized controlled feasibility trial. JMIR Res Protoc 2016;5:e244.
3. Hervey-Jumper SL, Berger MS. Maximizing safe resection of low- and high-grade glioma. J Neurooncol 2016;130:269–282.
4. Sommer B, Grummich P, Coras R, et al. Integration of functional neuronavigation and intraoperative MRI in surgery for drug-resistant extratemporal epilepsy close to eloquent brain areas. Neurosurg Focus 2013;34:E4.
5. Gabarros A, Young WL, McDermott MW, et al. Language and motor mapping during resection of brain arteriovenous malformations: indications, feasibility, and utility. Neurosurgery 2011;68:744–752.
6. Meng L, Weston SD, Chang EF, et al. Awake craniotomy in a patient with ejection fraction of 10%: considerations of cerebrovascular and cardiovascular physiology. J Clinical Anesth 2015;27:256–261.
7. Meng L, Han SJ, Rollins MD, et al. Awake brain tumor resection during pregnancy: decision making and technical nuances. J Clin Neurosci 2016;24:160–162.
8. Balogun JA, Khan OH, Taylor M, et al. Pediatric awake craniotomy and intra-operative stimulation mapping. J Clin Neurosci 2014;21:1891–1894.
9. Hervey-Jumper SL, Li J, Lau D, et al. Awake craniotomy to maximize glioma resection: methods and technical nuances over a 27-year period. J Neurosurg 2015;123:325–339.
10. Dziedzic T, Bernstein M. Awake craniotomy for brain tumor: indications, technique and benefits. Expert Rev Neurother 2014;14:1405–1415.
11. Brown T, Shah AH, Bregy A, et al. Awake craniotomy for brain tumor resection: the rule rather than the exception? J Neurosurg Anesthesiol 2013;25:240–247.
12. Hervey-Jumper SL, Berger MS. Technical nuances of awake brain tumor surgery and the role of maximum safe resection. J Neurosurg Sci 2015;59:351–360.
13. Groshev A, Padalia D, Patel S, et al. Clinical outcomes from maximum-safe resection of primary and metastatic brain tumors using awake craniotomy. Clin Neurol Neurosurg 2017;157:25–30.
14. Beez T, Boge K, Wager M, et al. Tolerance of awake surgery for glioma: a prospective European Low Grade Glioma Network multicenter study. Acta Neurochir 2013;155:1301–1308.
15. Milian M, Tatagiba M, Feigl GC. Patient response to awake craniotomy—a summary overview. Acta Neurochir 2014;156:1063–1070.
16. Meng L, Berger MS, Gelb AW. The potential benefits of awake craniotomy for brain tumor resection: an anesthesiologist's perspective. J Neurosurg Anesthesiol 2015;27:310–317.
17. Howe KL, Zhou G, July J, et al. Teaching and sustainably implementing awake craniotomy in resource-poor settings. World Neurosurg 2013;80:e171–e174.
18. Conte V, L'Acqua C, Rotelli S, et al. Bispectral index during asleep–awake craniotomies. J Neurosurg Anesthesiol 2013;25:279–284.
19. Rajan S, Cata JP, Nada E, et al. Asleep–awake–asleep craniotomy: a comparison with general anesthesia for resection of supratentorial tumors. J Clin Neurosci 2013;20:1068–1073.
20. Lin N, Han R, Zhou J, et al. Mild sedation exacerbates or unmasks focal neurologic dysfunction in neurosurgical patients with supratentorial brain mass lesions in a drug-specific manner. Anesthesiology 2016;124:598–607.
21. Kulikov AS, Kobyakov GL, Gavrilov AG, et al. Awake craniotomy: analysis of complicated cases. Zh Vopr Neirokhir Im N N Burdenko 2015;79:15–21.
22. Sivasankar C, Schlichter RA, Baranov D, et al. Awake craniotomy: a new airway approach. Anesth Analg 2016;122:509–511.
23. Deras P, Moulinie G, Maldonado IL, et al. Intermittent general anesthesia with controlled ventilation for asleep–awake–asleep brain surgery: a prospective series of 140 gliomas in eloquent areas. Neurosurgery 2012;71:764–771.
24. Potters JW, Klimek M. Awake craniotomy: improving the patient's experience. Curr Opin Anaesthesiol 2015;28:511–516.
25. Breshears JD, Molinaro AM, Chang EF. A probabilistic map of the human ventral sensorimotor cortex using electrical stimulation. J Neurosurg 2015;123:340–349.
26. Roux FE, Miskin K, Durand JB, et al. Electrostimulation mapping of comprehension of auditory and visual words. Cortex 2015;71:398–408.
27. Gras-Combe G, Moritz-Gasser S, Herbet G, et al. Intraoperative subcortical electrical mapping of optic radiations in awake surgery for glioma involving visual pathways. J Neurosurg 2012;117:466–473.
28. Talacchi A, Santini B, Casartelli M, et al. Awake surgery between art and science. Part II: Language and cognitive mapping. Funct Neurol 2013;28:223–239.
29. Sokhal N, Rath GP, Chaturvedi A, et al. Anaesthesia for awake craniotomy: a retrospective study of 54 cases. Indian J Anaesth 2015;59:300–305.
30. Nossek E, Matot I, Shahar T, et al. Intraoperative seizures during awake craniotomy: incidence and consequences: analysis of 477 patients. Neurosurgery 2013;73:135–140.
31. Nossek E, Matot I, Shahar T, et al. Failed awake craniotomy: a retrospective analysis in 424 patients undergoing craniotomy for brain tumor. J Neurosurg 2013;118:243–249.
32. Flexman AM, Ng JL, Gelb AW. Acute and chronic pain following craniotomy. Curr Opin Anaesthesiol 2010;23:551–557.
33. Flexman AM, Meng L, Gelb AW. Outcomes in neuroanesthesia: what matters most? Can J Anaesth 2016;63:205–211.
34. Gruenbaum SE, Meng L, Bilotta F. Recent trends in the anesthetic management of craniotomy for supratentorial tumor resection. Curr Opin Anaesthesiol 2016;29:552–557.
35. Wigmore TJ, Mohammed K, Jhanji S. Long-term survival for patients undergoing volatile versus IV anesthesia for cancer surgery: a retrospective analysis. Anesthesiology 2016;124:69–79.