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Intraoperative neurological monitoring in awake craniotomy

Kiyotaka Sato[1] and Masato Kato[2]

[1] Department of Neuroanesthesia, Kohnan Hospital, 4-20-1 Nagamachiminami, Sendai 982-8523, Japan
[2] Department of Anesthesiology and Perioperative Medicine, Tohoku Postgraduate School of Medicine, Sendai, Japan

K. Sato

Intraoperative neurological monitoring in neurosurgery

Neurological monitoring methods were developed for the preservation of neurological function and some became necessary in neurological surgery. About 10 years ago, established methods were rare, and classical EEG, auditory brainstem response (ABR), and somatosensory-evoked potential (SEP) methods were indicated for some kinds of neurosurgery. But now, motor-evoked potential (MEP) is becoming popular, and visual evoked potential (VEP), ocular movement nerves, and lower cranial nerves are monitored during neurosurgery. In addition to these electrophysiological methods, the measurement of carotid blood flow, cortical blood flow, blood velocity, and regional oxygen saturation is used in neurosurgery.

Address correspondence to: K. Sato
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Many kinds of neurological monitoring are available now; however, language function cannot be monitored under general anesthesia. For this, the patients are awakened and neurological function is evaluated, a procedure called "awake craniotomy". In awake craniotomy, not only language function but also motor or sensory function can be evaluated, and this may be the ultimate method for monitoring neurological function. However, the patient's understanding and cooperation is necessary and position of the patient during the procedure has to be restricted, and this cannot be indicated in every case.

Aim of awake craniotomy

In the treatment of glioma, the aggressive removal of tumor cells prolongs patients' survival [1,2]. But the extent of tumor cell removal is restricted when the tumor exists near or in the language or motor area and pyramidal tract, because of the need for preservation of brain function [3]. In aggressive resection, it is necessary to reveal the functional distribution of the brain to preserve neurological function [4]. Preoperative evaluation is becoming more accurate and detailed. For example, functional magnetic resonance imaging (fMRI), and magnetoencephalography (MEG) show the primary motor and sensory cortexes [5], while fiber tractgraphy indicates the pyramidal tract. Intraoperatively, the central sulcus and primary motor and sensory cortexes are estimated by SEP and MEP. However, for the accurate mapping of functional distribution, especially language function, the patient should be awakened during craniotomy [6]. For safe anesthetic management in awake craniotomy, a guideline was published by the Japanese Society of Neuroanesthesia and Critical care (Table 1) [7].

Table 1. Summary of the guideline for anesthetic management of awake craniotomy published by the Japanese Society of Neuroanesthesia and Critical Care [7]

1. Important issues
   Careful planning of surgery and anesthesia
   Trained anesthesiologist
   Cooperation among members of surgical team
   Propofol as basic sedative
   Careful titration of anesthetic; maximal analgesia with local anesthetic
   Antiemesis
   Prompt treatment for convulsion
2. Premedication
   No sedative, benzodiazepine if necessary
   Anticonvulsive if requested
3. Basic monitoring
   ECG, IABP, Sp_{O_2}, ET_{CO_2}, urinary output, body temperature
   IV lines for intravenous anesthetic and transfusion
   Propofol by TCI recommended
4. Induction
   Positioning, monitoring, O_2 inhalation
   Propofol with or without fentanyl (and/or remifentanil), minimal fentanyl before functional mapping
   Spontaneous breathing or assisted/controlled ventilation with LMA
   Urinary catheter
   Analgesia with local anesthetic; peripheral nerve block and infiltration
5. Intraoperative awakening
   No sedative or analgesics
   Minimal propofol if necessary, remifentanil not recommended under spontaneous breathing
   Additional local anesthesia if complaint of pain
   If there is nausea/vomiting, suspend the surgical procedure; give metoclopramide and $5HT_3$ antagonist; propofol if necessary
   If there is convulsion, discontinue electrical stimulation; cold saline on brain surface; small dose of propofol, phenytoin, midazolam, or other sedative if necessary
7. Reinduction, closure
   Induction with propofol with/without fentanyl (and/or remifentanil) when patient is not required to be conscious
   Spontaneous breathing or assisted/controlled ventilation with LMA
   Additional local anesthetics if required
8. Awakening and discharge
   Discontinue anesthetics
   Discharge after recovery of consciousness and adequate breathing.

Fundamentals of anesthetic management for awake craniotomy

Points for the anesthetic management of awake craniotomy are: (1) detailed explanation given to the patient and the patient's understanding of the procedure, (2) airway management, (3) control of seizure, and (4) anxiolysis.

It is necessary that the patient is fully awake, feels comfortable, and is cooperative, and it is important that the patient understands and agrees to the procedure. Also, a relationship of mutual trust among the patient, anesthesiologist, neurosurgeon, and operating room (OR) staff is important. The administration of sedatives must be kept to a minimum to ensure that the patient is well awake during functional mapping.

Usually, the patients are managed under spontaneous breathing, without a particular airway device; therefore, tailored administration of sedatives is necessary. Recently, the laryngeal mask airway (LMA) was introduced for awake craniotomy, and airway management during craniotomy and closure became less difficult. However, insertion of an LMA during the procedure is not so easy because of the restricted space for anesthesiologist.

The patients in whom awake craniotomy is performed have a brain tumor or epilepsy, and seizure is likely to occur. Especially during functional mapping, the brain is stimulated electrically and seizure is sometimes induced. When seizure activity is recognized in the EEG, the stimulation should be discontinued and treatment begun.

It is a particular concern for the patient that their own brain is exposed and touched by the surgeon, and the patient may become restless. Therefore, factors causing a feeling of insecurity in the patient should be resolved

before the procedure, and tender care is required. In awake craniotomy, analgesia should be obtained with local anesthesia. Pain before the procedure increases patients' anxiety, and sedation during peripheral nerve block should be enough.

In the anesthesia guideline for awake craniotomy, detailed planning; a system of cooperation among anesthesiologists, neurosurgeons, neuropsychologists, and OR staff; propofol as the main sedative; maximal analgesia with local anesthetics; the importance of antiemesis; and the control of seizures are pointed out as basics of anesthetic management.

Preoperative evaluation and premedication

The usual preoperative evaluation for general anesthesia is mainly on physical status, but mental status is also important for awake craniotomy. The anesthesiologist has to confirm these issues: that patients have the will to lie on the operating table for a long time with restriction of their movement, they do not have claustrophobia, they can make a personal request correctly, and they have enough intelligence to answer neuropsychological test questions.

An insignificant problem in the usual general anesthesia may become serious in awake craniotomy. Cough when the brain is exposed induces projection of the brain tissue and contusion at the bone edge. Any upper airway infection, or nasal allergy should be well treated. Secondary gastroesophageal reflux is a serious problem, because the airway is not completely secured in awake craniotomy; patients with diabetes mellitus or obesity are at particular risk of this reflux.

Premedication with a sedative is not allowed, so that it will be certain that the patient will be well awakened during functional mapping. On the morning of the surgery, steroid, phenytoin, glycerol, or mannitol is administered if requested by the surgeon.

Monitoring during the procedure and preparation of anesthesia

ECG, invasive arterial blood pressure (IABP), pulse oximetry ($S_{p_{O_2}}$), end-tidal CO_2 (ET_{CO_2}), urinary output, and body temperature are monitored during anesthesia. Venous lines for anesthesia and fluid infusion or transfusion are established. It is advisable to infuse propofol by target controlled infusion (TCI), because delicate control is necessary when anesthesia is maintained with spontaneous breathing. Assisted or controlled ventilation is possible using an LMA or other device. During craniotomy and closure, we now use an LMA and manage the patient under controlled ventilation, and airway management has become easier.

The preparation of anesthesia is the same as that for the usual general anesthesia. Emergency airway equipment should be beside the anesthesiologist.

Positioning, induction of anesthesia, and local analgesia

Awake craniotomy is indicated for a lesion near the language area; therefore, the position of the patient is semilateral or lateral. Pressure points should be protected by pads and it has to be ascertained that the patient is satisfied with the positioning. It is important that the axis of head and body is not too distorted. The neck is put a little extended so that the airway is easily established. The intracranial pressure (ICP) is decreased by elevation of the upper half of the body (Fig. 1). After confirmation of ECG, blood pressure (BP), and $S_{p_{O_2}}$, inhalation of oxygen is commenced. Anesthesia is induced with 2–3 $mg \cdot kg^{-1}$ of propofol and 1–2 $\mu g \cdot kg^{-1}$ of fentanyl, and the LMA is inserted. In principle, a muscle relaxant is not employed. Anesthesia is maintained with propofol under assisted or controlled ventilation. Remifentanil is useful under controlled ventilation with an LMA. When anesthesia is maintained under spontaneous breathing, propofol is infused using TCI. The target is increased in steps, ascertaining the breathing. After induction, a urinary catheter is inserted and an arterial line is established. Local analgesia is obtained by local infiltration at incision, and a peripheral nerve block with a 1:1 mixture of 0.5% lidocaine with epinephrine and 0.375% ropivacaine. The supraorbital, zygomatico-temporal, auriculo-temporal, greater occipital, and lesser occipital nerves are blocked. More sedative is necessary at injection of local anesthesia. 60–80 ml of the above local anesthetic mixture is used. At our institute the patient's head is not fixed with pins, because this is a major cause of discomfort for the patient [8], and because, if this is done, insertion of the LMA at closure becomes more difficult. Sufficient local analgesia is necessary even when remifentanil is used because the patients are awakened immediately after the craniotomy. After local anesthesia, craniotomy is performed under titration of propofol infusion with or without remifentanil. When the brain surface is exposed, the propofol is discontinued and the patient is awakened. The patient may not recognize their own situation and may become restless. In such cases, intraoperative functional mapping is abandoned.

Intraoperative awakening and functional mapping

About 15 min after the discontinuation of propofol and remifentanil, the patient is awakened. The LMA is re-

Fig. 1a,b. Position of the patient before (**a**) and after (**b**) draping. The axis of the head and body is not too distorted. The neck is a little extended so that the airway is easily established. The upper half of the body is elevated

moved and local anesthetic is added if necessary. From the results of SEP and MEP, the central sulcus, and motor and sensory cortexes are identified and the baseline EEG is recorded. Neuropsychological testing, including testing of language function, is performed (Fig. 2), without any sedative; the brain surface is electrically stimulated, functional localization is mapped, and the region of resection is decided. At some institutes, low doses of propofol, dexmedetomidine, and remifentanil are used.

Epileptic discharge is often seen during electrical stimulation and one should notice its intensity and duration. The discharge disappears with the discontinuation of electrical stimulation in most cases, but if it continues or spreads, the brain surface is cooled with cold saline. If an epileptic seizure becomes symptomatic, a sedative dose of propofol is administered. If the seizure becomes generalized, aggressive antiepileptic treatment with additional propofol, midazolam, or thiopental should be considered, while securing the airway.

If the patient suffers with nausea and vomiting, surgical manipulation is discontinued and metoclropramide or a 5-HT antagonist is administered. If the symptoms are severe, a low dose of propofol may be used.

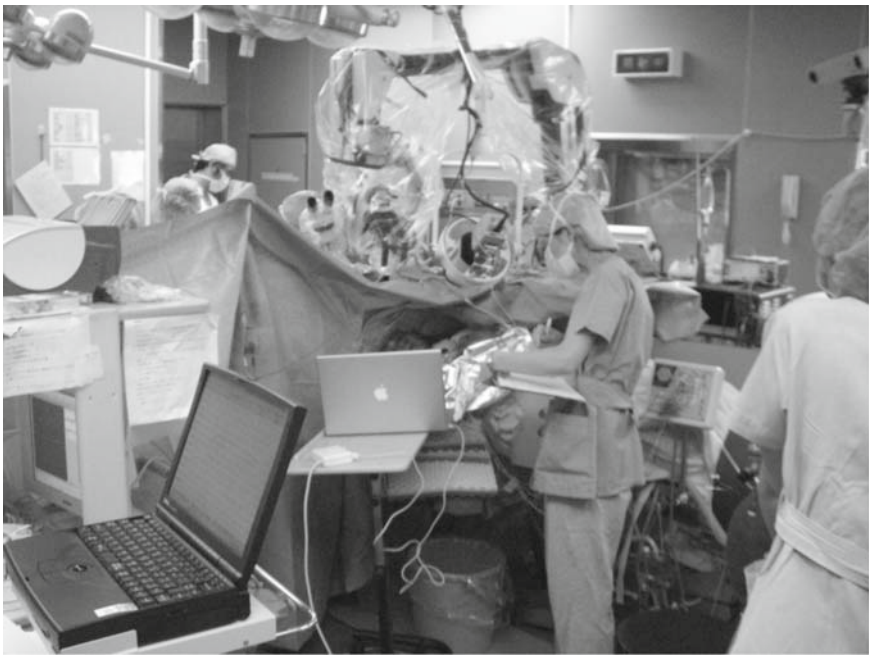

Fig. 2. Picture taken during functional mapping. The neurosurgeon applies electrical stimulation and a neuropsychologist diagnoses the changes in brain function, observing the EEG

Reinduction and closure

After the phase in which cooperation by the patient is required, anesthesia is induced again with propofol and fentanyl (or remifentanil) and the LMA is inserted. At first the brain is exposed and a sufficient dose of anesthetic is required. The working space for the anesthesiologist is restricted at this time, and insertion of the LMA is done with a little difficulty. If the airway management is difficult, the operating field is draped and general anesthesia with tracheal intubation may be induced.

When the procedure is completed, propofol and remifentanil are discontinued and the LMA is removed after confirmation of awakening.

Conclusion

The aim of awake craniotomy is to achieve the most effective resection with minimal neurological deficit, although one cannot always meet the ideal [9]. However, we are sure that there are some patients who benefit from the procedure. For the procedure to succeed, a reliable relationship with the patient and cooperation among anesthesiologist, surgeon, and OR staff is necessary.

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