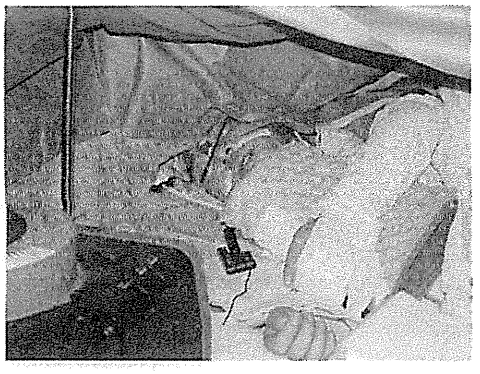

**Fig. 2 Conditions used for the first case in the Department of Neurosurgery of Tohoku University (1996).**

(Fig. 2), and transparent drapes may be used to allow vision.[6] Surgery takes a long time and osmotic diuretics such as mannitol may be used because of the inability to employ hyperventilation to control brain swelling, so continuous urine flow is required.

If intraoperative motor functional mapping is done under general anesthesia, unlike awake anesthesia, freer setting of the posture and head position (including use of the prone position) is available. However, functional brain mapping takes time to perform without administration of muscle relaxants, so whether the patient will feel comfortable in an unforced posture should be considered when setting the posture.

*Posture setting on the day of surgery*: Even if the posture has already been confirmed on the day before surgery, take enough time to set the patient's posture again and ensure that he/she is comfortable. To confirm whether the patient feels comfortable or not, hold a conversation and do not induce anesthesia until the completion of posture setting.

*Head fixation*

There is no consensus at this time about whether head fixation should be done or not. If we give first priority to the patient's comfort, no fixation would seem to be more desirable. However, lack of fixation will lead to constant movement of the surgical field. To continually respond to unexpected movements for a long time when manipulating deep brain regions or blood vessels is very stressful for surgeons. For surgery combined with awake functional brain mapping/monitoring, which is based on cooperation and achieving a balance between the surgeons and the patient, determine whether head fixation should be used or not after careful consideration at each institution. Even without head fixation, continuous navigation is available[5] by fixing the reference points to the skull.[4]

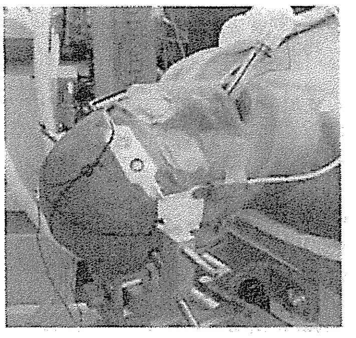

**Fig. 3 Approach with head fixation.**

*[Commentary on approach with head fixation]*

The advantages of head fixation include a fixed operating field and complete fixation of the conventional navigation system, retractor, electroencephalograph, or other instruments, so that the surgeon can operate as under general anesthesia. The disadvantages of this approach include more patient discomfort compared with the absence of head fixation, due to pain at the pin fixation sites, and difficulty of moving the body and changing the head position. Also, treatment of vomiting or convulsions and reintubation may be difficult, so sufficient simulation is necessary. A patient with a left frontal lobe glioma receives 4-point fixation after insertion of a laryngeal mask (Fig. 3). As with 3-point fixation, it is difficult to rotate and move the head after application of 4-point fixation, so simulation of emergency situations is very important.

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**2-3. Awake state and surgery: Status of anesthesia and status of electrical stimulation during resection**

*[Recommendation]*

Resection is often performed under anesthesia or sedation, and the methods vary among institutions. With subcortical mapping, electrical stimulation needs to be continued even during resection. There is no established method at this time and the value of the procedure is uncertain.

*[Commentary]*

Although the use of sedation is common during resection of the lesion, it is done on a case-by-case basis or never performed at some institutions because it is still controversial. Propofol is often used, but dexmedetomidine, sevoflurane, nitrous oxide, etc., can also be employed.

For subcortical mapping, electrical stimulation needs to be continued even during resection. However, there is no established method of subcortical stimulation and the methods employed vary among institutions at present. For subcortical mapping of the corticospinal tract, the method of recording the electromyogram by using Ojemann-type bipolar electrodes as in cortical mapping seems to be employed relatively often. With bipolar recording, however, the stimulation range is limited to the immediate vicinity of the electrodes and injury has often already occurred when a response is detected. If the presence of the corticospinal tract cannot be predicted at a certain distance, subcortical mapping may well be useless. A method of recording corticospinal motor-evoked potentials (D-wave) that descend through the corticospinal tract from spinal epidural electrodes for subcortical mapping is being discussed. The amplitude of D-waves evoked by monopolar stimulation may reflect the distance between the stimulation points and the corticospinal tract to some degree, so the method of recording the D-wave amplitude under given stimulus conditions seems to be promising.

Also, in subcortical mapping of language functions, conventional bipolar stimulation limits the range as for mapping the corticospinal tract, so whether language area-derived speech arrest can be certainly detected is unclear and the reliability of subcortical electrical stimulation during resection is difficult to determine.

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**2-4. Conditions and timing of stimulation**

**2-4-1. Cortical stimulation: type of electrode, intensity of stimulation, and duration**

*[Recommendation]*

In the setting of brain electrical stimulation for functional mapping, because of its effect and to maintain the safety of the brain tissues, the following methods of using probe electrodes and subdural electrodes are recommended:

Probe electrodes: Interpolar distance of 5 mm and diameter of 1 mm for bipolar electrodes or diameter of 1 mm for monopolar electrodes; square wave pulses (0.2 or 0.3 or 1 msec) with alternating polarity and frequency of 50 or 60 Hz, and stimulus duration of up to 4 seconds; and current from 1.5 (or 2) mA with maximum intensity of 16 mA.

Subdural electrodes: Interpolar distance of 5 mm to 1 cm and diameter of 3 mm for bipolar electrodes; square wave pulses (0.2 or 0.3 msec) with alternating polarity and frequency of 50 or 60 Hz, and stimulus duration of up to 10 seconds; and current from 1 mA with maximum intensity of 16 mA.

*[Commentary]*

Stimulation conditions vary among the types of electrode and purposes of functional mapping. The recommendations cover typical methods for cortical language mapping. When stimulating the primary motor area under awake conditions, use of low frequency stimulation or one to five repetitive stimuli is desirable to prevent convulsions.

For identification of false-positive responses to peripherally spreading electrical stimulation, afterdischarges should be monitored.[1,2] Cortical excitability differs between children and adults and also varies between individuals, so false-negative results can occur.

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**2-4-2. Subcortical stimulation: type of electrode, intensity of stimulation, and duration**

*[Recommendation]*

The conditions for stimulation are the same as those for "cortical stimulation."

Alternative method for stimulation (subcortical): 0.2 msec, 50 Hz, stimulus duration of up to 4 seconds, from 1 mA to maximum intensity of 20 mA.

Implanted subdural electrode (deep electrode): Used for hippocampal lesions. The interpolar distance is 1 cm or 5 mm.

*[Commentary]*

Experience shows that responses are often identified by the same tasks and current intensity as with cortical stimulation. If maximum resection is performed while checking the response to subcortical stimulation, 80% of patients develop transient neurological symptoms, but 94% of them recover within 3 months.[1] Subcortical stimulation also allows identification of the following language-related fibers, by which various findings have been obtained[2,3]: superior longitudinal fasciculus, arcuate fasciculus, subcallosal fasciculus, inferior fronto-occipital fasciculus, inferior longitudinal fasciculus, uncinate fasciculus, orofacial motor fibers, etc.

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**2-5. Treatment of convulsions**

*Risk*: Convulsion can develop during intraoperative mapping and tumor resection.

*Measures*: Reduce the stimulus intensity. Do not persist with mapping. For tumors near the motor cortex, raise the concentrations of phenobal and phenytoin to the upper normal limits and check the levels every 2 hours during surgery. If the levels are lower than the limits, appropriately administer 250 mg of intravenous phenytoin and 100 mg of intramuscular phenobal to increase the concentrations to the upper limits. If convulsions occur, put cold water or cold artificial cerebrospinal fluid (e.g., Artcereb®; Otsuka Pharmaceutical Factory, Inc., Tokyo) on the brain surface and wait until the convulsions cease. If convulsions occur frequently, switch to general anesthesia and then switch back to awake surgery if possible after adequately raising the concentrations of anticonvulsants. (For tumors near the motor cortex, surgery can continue while checking the motor-evoked potentials [second best method].)

**2-6. Necessity and usefulness of confirming afterdischarges: methods and evaluation**

*[Recommendation]*

Confirmation of stimulation-induced convulsions by evaluating the occurrence of afterdischarges on the electrocorticogram should be a basic procedure.[2] At the very least, until the number of cases experienced by the institution increases, it is essential that the stimulation conditions are standardized, and the method of functional evaluation is established. The risk of mistakenly identifying motor, sensory, and language disorders induced by development of brain dysfunction at distant sites because of stimulation-induced afterdischarges should be avoided. To confirm whether electrical stimulation is actually being delivered (i.e., the current is flowing), electroencephalography is useful. Position the electrocorticographic electrodes and record the electrocorticogram without stimulation (Fig. 4). Place small pieces of paper with numbers, etc. on the brain surface so that surgeons, staff performing electrophysiological mapping, and staff performing higher function examination can mutually confirm the stimulation sites. Stimulate the brain surface for 2 to 3 seconds by applying biphasic rectangular pulses of 50 Hz and 0.3 msec pulse width with

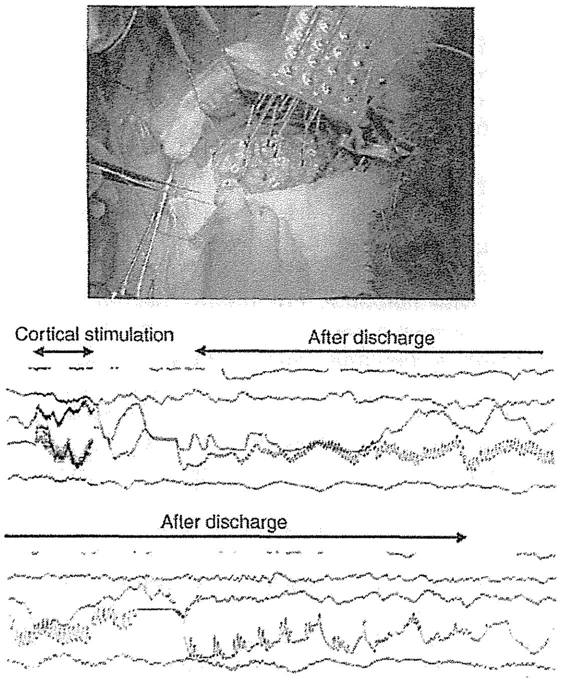


**Fig. 4 Setting the electrocorticograph and electrocorticographic stimulation with bipolar electrodes.**

bipolar electrodes using an inter-electrode distance of 5 mm. For stable stimulation, the brain surface should be kept moist by using a nebulizer. Increase the stimulus current from 4 mA in increments of 1 mA and determine the optimal current for achieving stable muscle contraction without afterdischarges in the cortical electroencephalogram. Under the above conditions (which we use), effective stimulation is often obtained at 8–11 mA. Under awake anesthesia, a lower stimulus current is optimal and 4–8 mA is often used. For the sensory areas, because instantaneous brain-surface stimulation with a low current leads to complaints of numbness and discomfort by the patient, it is desirable to initiate mapping of the sensory areas first. Stimulation is done at the sites predicted using the neuronavigation system or from anatomical landmarks such as sulci, gyri, and superficial veins, and from the somatosensory-evoked potentials obtained by median nerve stimulation or labial stimulation, and the aim is to achieve effective results from the first stimulus. The motor cortex does not cover all of the precentral gyrus, but lies between the anteroposterior regions on the side of the central sulcus. Therefore, stimulation should be applied along the central sulcus first. Bipolar electrodes are used to apply stimulation perpendicular to the central sulcus. If the craniotomy does not extend as far as the finger area during tumor resection in the frontal opercular region, you can place strip electrodes across the central sulcus underneath the dura for stimulation. Electromyography[3] is not performed for all muscles, so the extremities and face must be carefully observed at sites where stimulation is expected to induce movement.

After completion of mapping of the motor and sensory areas, initiate functional language mapping. First, ask the patient to count from 1 to 50 continuously. At this time, increase the stimulus current in increments of 1 mA, while confirming that there are no afterdischarges in the cortical electroencephalogram. A current of up to about 16 mA may be used. Record the sites associated with speech arrest and hesitation. When stimulating the lower portion of the precentral gyrus, a negative motor response[1] may inhibit speech. One of the methods for confirming this is to apply stimulation to the brain surface i) while instructing the patient to project the tongue and move it from side to side, ii) while continuing countermovement of the thumb and forefinger, and iii) while bending and extending the ankle joints. If arrest of movement of the tongue or countermovement of the fingers and movement of the ankle joints is observed, the inhibition is associated with a negative motor response and not with language dysfunction. By these procedures, the optimal stimulus current can be determined and the frontal language areas identified to some extent. Then, perform object naming while continuing stimulation.

No abnormalities of counting does not always correspond with no disorders of object naming. Show the patient slides for approximately 2–3 seconds each. Assess whether there is speech arrest, hesitation, or wrong answers after presenting the stimulus. If these occur, you always need to confirm whether they are induced by actual stimulation of language function areas, fatigue, inability to see the slides, or the development of seizures. Using the sentence pattern for naming "This is ###" allows us to determine whether abnormalities are associated with arrest of speech itself by stimulation of the tongue motor areas or negative motor areas, or are due to stimulation of language function areas. Because identification of language areas needs repeated confirmation of the results, patients have to expend a large amount of energy. Therefore, functional brain mapping/monitoring requires complete cooperation of the patient.

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### 2-7. Complications other than convulsions and countermeasures

#### 2-7-1. Pain

*Risk*: Pain can develop in the skin, muscles, dura mater, and sites on the underside of the body.

*Measures*: Ask the patient about painful sites and treat with local anesthesia as far as possible. Fix the head with 3 or 4 pins (if you use a head frame) and place something soft under the body to allow for movement. For surgery on the temporal lobe, turn the waist up as far as possible to prevent pain caused by compression of the underside of the waist, which often occurs in the lateral position.

#### 2-7-2. Air embolism

*Risk*: Tumors of the inner motor cortex are associated with a risk of air embolism because the surgical field is placed in the highest position.

*Measures*: Bend the head forward without affecting respiration, raise the lower extremities, and bend the abdomen slightly forward to increase the jugular venous pressure. Cover the skull with fibrin, thrombin, and Calcicol immediately after opening the skull. Keep the head down until the dura mater is opened and then gradually raise the head while observing $SaO_2$. If there are symptoms such as cough and a decrease of $SaO_2$, immediately put the head down and hold the neck.

#### 2-7-3. Delirium and emotional incontinence

*Risk*: There are some reports of delirium developing when anesthesia is stopped to obtain the awake state. Intraoperative anxiety and pain may also cause emotional incontinence.

*Measures*: Avoid decreasing the level of consciousness by use of local anesthetic as far as possible. Play the patient's favorite music or take measures to avoid anything that makes the patient uncomfortable so that the patient can undergo surgery easily. Depending on the patient's condition and the progress of surgery, decide whether it should be continued under awake conditions, should be continued without awake conditions, or should be discontinued. If continuation of awake conditions is needed, deal with the patient's complaints (primarily pain) as far as possible, but sometimes encourage the patient to tolerate the discomfort.

#### 2-7-4. Increased intracranial pressure

*Risk*: Increased intracranial pressure may develop in patients with brain tumors, but seldom in those with epilepsy. During awake surgery, arterial carbon dioxide tension ($PaCO_2$) tends to be higher than under general anesthesia, leading to a higher risk of increased intracranial pressure.

*Measures*: If there is evidence of increased intracranial pressure on imaging studies, general anesthesia should be employed. If awake surgery is considered to be absolutely necessary, the decision can be made after dural incision following standard intubation. If there is no brain swelling induced by increased intracranial pressure, switch to awake surgery after extubation. If brain swelling occurs during awake surgery, consider switching to general anesthesia.

#### 2-7-5. Others

There are reports about the development of air embolism and pneumonia, although whether these are characteristic problems of awake surgery is controversial. Air embolism can be caused by raising the head excessively (for example, locating the operating field at the highest position in the motor cortex 1). As with general anesthesia, bend the head forward without affecting the respiration, raise the lower extremities, and bend the abdomen slightly forward to increase the jugular venous pressure. Cover the skull with bone wax, fibrin, and thrombin immediately after opening the bone. Keep the head down until the dura mater is opened and then gradually raise the head while observing arterial oxygen percent saturation ($SaO_2$). If there are symptoms such as cough and decrease of $SaO_2$, immediately put the head down and hold the neck. Also, for prevention of pneumonia, it seems to be important to prevent lowering of consciousness and vomiting (refer to the section on anesthetic management for details about dealing with nausea and vomiting).

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### 2-8. Decision-making based on the results of stimulation

#### 2-8-1. Epilepsy

*[Recommendation]*

In the case of epilepsy, consider whether the results of functional brain mapping by electrical stimulation are reliable. Epileptic foci often include functional brain sites and the extent of resection influences postoperative seizure control. It is desirable to fully assess the extent and overlap of epileptogenic foci and functional sites, and then carefully discuss the indications for resection of functional areas in individual cases depending on the pathological condition.

*[Commentary]*

Epilepsy is a functional disease, and the presence or absence of functional disorders associated with surgery influences the indications for surgery. For decision-making about additional surgical treatment and the extent of resection in individual cases, it is important to fully understand the pathology of epilepsy. Assessment of the results obtained by functional brain mapping with electrical stimulation requires attention to the following points. In patients with epilepsy, cortical excitability at functional sites is variable and both false-positive and false-negative results of electrical stimulation can occur.[1] Displacement of brain function sites from their anatomical positions can also occur. Therefore, functional brain mapping by electrical stimulation should be performed carefully, and it is desirable to undertake subdural electrode placement with reference to the results of various noninvasive physiological tests, such as fMRI, positron emission tomography, and MEG, for detailed mapping. The use of brain surface electrodes allows for complementary cortical function testing to assess the development of symptoms and to measure evoked potentials during voluntary activity after electrical stimulation. Epileptogenic foci often overlap with functional sites in the brain. In such a situation, resection of the focus is superior to multiple subpial transection and more complete resection results in better postoperative control of epileptic seizures.[2] It is reported that 0% to 63% of patients develop persistent functional disorders after resection of functional brain areas involved by epileptic foci. However, due to the small number of cases, it is unclear whether we should resect all the functional sites, whether we should consider the resection of sites with a possible compensatory function, and how to decide on the discontinuation of resection.


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#### 2-8-2. Brain tumors

*[Recommendation]*

Functional tissues revealed by mapping should be preserved unless consent giving priority to resection is obtained or the surgeon determines that resection is feasible. Accumulate experience with mapping and pay careful attention to false-positive results (nonfunctional brain tissues despite positive findings on stimulation).

*[Commentary]*

Intraoperative functional testing during awake surgery involves mapping by electrical stimulation and monitoring to observe neurological findings. Mapping is performed to identify functional brain tissues and to prevent neurological complications induced by resection and damage to functional tissues during brain tumor removal. Therefore, the sites where symptoms occur during mapping should be preserved in principle because they are likely to be functional tissues. If they are not preserved, we see no point in performing awake surgery. However, if tumors coexist with functional tissues[2] and preoperative consent has been obtained, functional tissues may not be preserved if the decision is confirmed to give priority to tumor resection after accepting the risk of complications and the fact that postoperative symptoms are likely to develop even with a response (e.g., negative motor areas in the supplementary motor cortex). Because responses are sometimes false-positive, you should acquire proficiency in mapping. False-positive findings are primarily obtained because awake conditions are poor and do not allow patients to perform their tasks, and sometimes because the basic conditions for the tasks are poor (e.g., the patient cannot see the screen because a drape covers his/her eyes). At our hospital, some patients could not perform the naming task due to inability to see the screen because of conjugate deviation induced by stimulation of oculomotor fibers, but they were regarded as having language arrest (the truth was recognized by reviewing videos). Recently, Berger et al.[1] have insisted on the validity of a "negative mapping strategy," suggesting that language areas do not have to be identified as a positive control (and major craniotomy does not have to be performed for identification), and that resection can be performed if language areas do not exist within the resection zone under certain conditions (60 Hz, maximum 6 mA). Given that this is a report from the most experienced institution, resection after identifying the language areas seems to be safer at less experienced institutions. It is significant that their report indicates that awake language mapping allows us to perform even aggressive resection with a very low incidence of complications and that a report on language mapping was published in a top clinical journal, suggesting that evaluation of its usefulness as a surgical procedure for glioma has been established.

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## II. ANESTHEIC MANAGEMENT FOR AWAKE CRANIOTOMY

### 1. Introduction

In the 1800s, resection of foci in epileptic patients was performed by craniotomy under local anesthesia.[6] With no electroencephalogram, direct stimulation of the cortex was employed to detect the epileptic focus and identify functionally important sites, which seems to be the prototype of current awake craniotomy. In the 1900s, with addition of sedation, surgery became more comfortable for patients.[8] Using codeine, thiopental, and meperidine, management was conducted under spontaneous respiration or partially by tracheal intubation. Epileptic surgery then came to emphasize intraoperative electroencephalography.[9] In the 1960s, neuroleptanalgesia was introduced into anesthesia, and the combination of droperidol and fentanyl was considered especially useful for surgery in patients with temporal lobe epilepsy because it had less influence on the intraoperative electroencephalogram.[5] In addition, the development of a long-acting local anesthetic, bupivacaine, facilitated awake craniotomy. As a result, many procedures for intractable epilepsy employed neuroleptanalgesia.[1,7] Thereafter, short-acting analgesics such as sufentanil and alfentanil were introduced.[4] Propofol was introduced for awake craniotomy because it is short-acting and has anticonvulsant and antiemetic effects.[10] It is now widely used as the main sedative. Recently, new anesthetics such as dexmedetomidine[2] and remifentanil[3] have been introduced, while use of a laryngeal mask has been initiated for airway management.[11] Because procedures that are not necessary during ordinary general anesthesia, such as airway management and treatment of intraoperative convulsions, are required, we would like you to refer to these guidelines for reliable and safe anesthetic management. There is limited evidence about anesthetic management during awake craniotomy, so the methods in actual use and those recommended by the review committee are presented. Also, because there is "awake surgery" in the cardiac surgery field and the "wake-up test" in orthopedic surgery, we are using the term "awake craniotomy" here to distinguish awake brain surgery from those procedures.

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**2. Basic policy**

i) Communicate with the surgeons and operating room staff based on a detailed surgical and anesthetic plan.
ii) To handle intraoperative respiratory problems and rapidly changing risks, management and supervision by anesthesiologists who have acquired extensive experience with awake craniotomy is required.
iii) To safely manage rapidly changing intraoperative conditions, ensure that backup anesthesiologists are available in addition to the attending anesthesiologists.
iv) To allow smooth switching to general anesthesia if the anesthesiologist considers it difficult to continue awake craniotomy, establish a system for cooperation with the surgeons and operating room staff.
v) Do not use inhalational anesthetics that are absorbed and excreted by the respiratory system because a definitive airway is not established. (Inhalational anesthetics that could possibly cause an increase of brain volume should not be used because of the uncertain management of $PaCO_2$ during awake craniotomy.) Use propofol as the basic sedative.
vi) Because management is performed under spontaneous respiration, carefully titrate the sedative and analgesic drugs. Maximize the use of local anesthesia for analgesia. (During the unconscious period, management with controlled respiration via the laryngeal mask airway [LMA], etc. is available.)
vii) Take measures to prevent nausea and vomiting that could lead to respiratory complications.
viii) Electrical stimulation during functional mapping may induce convulsions, occasionally resulting in inability to continue the procedure, which then requires rapid countermeasures to be taken.

[*Commentary*]

Awake craniotomy was used for surgical treatment of epilepsy in the early 20th century, and then was applied to surgery for brain tumors, cerebral arteriovenous malformations, and cerebral aneurysms associated with important areas such as the motor or sensory cortex and language cortex.[2,3] The purpose of awake craniotomy is to prevent brain dysfunction induced by surgery and to precisely resect the disease focus in order to improve the patient's prognosis and quality of life. The purpose of anesthetic management is, while putting the patient's safety first, to remove psychophysical pain and allow the necessary surgery to be done. Each of the sections in these guidelines and the corresponding commentary describe the details of anesthetic management for awake craniotomy. Because there have not been enough randomized controlled studies of anesthetic management for awake craniotomy, management that is not based on such evidence in these guidelines is based on the methods recommended by institutions familiar with awake craniotomy. Therefore, if anesthetic management based on randomized controlled study evidence is reported in the future, these guidelines will be appropriately reviewed.

For successful awake craniotomy, the first point is that the patient's cooperation is essential. Second, preoperative and intraoperative communication and agreement among neurosurgeons, anesthesiologists, and operating room staff familiar with awake craniotomy is required. For anesthetic management, it is necessary to establish the airway, stabilize hemodynamics, and prevent increase of intracranial pressure. Because management of $PaCO_2$ is more difficult during awake craniotomy, inhalational anesthetics that could possibly increase brain volume should be avoided. Hence, sedation and general anesthesia with propofol is currently the standard for awake craniotomy. While the patient is unconscious, respiratory management with an LMA can be used. Each of the sections in these guidelines describes the details of respiratory management.

During awake craniotomy, because scalp block and infiltrational anesthesia for sufficient pain control require a large volume of local anesthetics, caution should be paid with regard to local anesthetic toxicity.[1] During awake craniotomy, it is also necessary to prevent adverse reactions such as nausea, vomiting, and convulsions, and to deal with such reactions immediately if they occur. If establishment of an airway is difficult or if other adverse reactions interfere with the patient's safety, after discussion between the anesthesiologists and neurosurgeons, awake craniotomy should be speedily discontinued and switching to general anesthesia should be considered.[4]

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### 3. Premedication

i) To allow complete intraoperative emergence, do not administer premedication that could possibly cause residual sedation.
ii) If there is no choice but to administer premedication, use a benzodiazepine that could possibly produce antagonism.
iii) Make a decision about premedication with anticonvulsants after consulting the patient's physician.

*[Commentary]*

During awake craniotomy, it is important for patients to be sufficiently awakened during surgery to perform language and motor tasks that yield reliable results, based on which the extent of resection is determined. Therefore, as a matter of principle, drugs that could affect emergence should not be administered. For successful awake craniotomy, it is crucial to build a relationship of trust among the patient, the surgeons, the anesthesiologists, and the operating room staff.[1] The establishment of such a patient-centered relationship reduces the need for sedatives. However, if sedatives have to be administered, benzodiazepines are recommended as antagonists are available. If surgery is being done for a tumor, hypercapnia induced by sedation can possibly result in an increase of intracranial pressure, and this requires special caution.

Convulsions are one of the most significant complications of awake craniotomy. Difficulty in ventilating the patient when convulsions persist and respiratory arrest occurs can lead to a fatal outcome. Because the patient's condition needs to be considered, preoperative administration of anticonvulsants should only be done after discussion with the attending physician. Note that propofol also has an anticonvulsant effect. With regard to other drugs such as H2 blockers that are administered during general surgery, the policy of the institution should be adopted.

Among antiemetics, metoclopramide hydrochloride (Primperan®; Sanofi-Aventis K.K., Tokyo) is not recommended because of potential adverse effects caused by enhanced peristalsis. Some reports of dexamethasone being administered to control the intracranial pressure and prevent vomiting have been described in other countries. However, this procedure is not covered by health insurance in Japan. Also, propofol has a useful antiemetic effect.

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### 4. Basic monitoring and preparation

i) Monitor the electrocardiogram, invasive arterial blood pressure, percutaneous oxygen saturation, expiratory partial pressure of carbon dioxide, urine volume, and body temperature.
ii) Create peripheral venous access for continuous administration of anesthetics and blood transfusion.
iii) Procedures are performed without a secure airway, so careful respiratory management is needed. Management can be done with spontaneous breathing or assisted ventilation via the LMA, etc.

*[Commentary]*

Basically, comply with the guideline of the Japanese Society of Anesthesiologists for installation of monitors. If sedation is used during awake craniotomy, regardless of the method of establishing the airway, different precautions from those during tracheal intubation should be taken. If a device such as the LMA is not used to establish the airway, precise management of $PaCO_2$ is difficult and careful observation is necessary to assess the frequency of breathing and the presence or absence of forced respiration. Therefore, for good anesthetic management, an environment that allows easy observation of the respiratory status is required, including use of transparent drapes to allow sufficient observation of the patient's mouth, neck, and chest. A stethoscope taped to the chest wall is one method. Some nasal cannulae have ports for measurement of expiratory carbon dioxide, but sometimes accurate data are not obtained, indicating limited usefulness. For management with an LMA, even if spontaneous ventilation is maintained, measure expiratory carbon dioxide tension and support respiration if necessary. Ventilation does not often allow for sufficient respiratory management, so an arterial cannula should be placed for easy arterial gas analysis when needed.

There have been reports of air embolism during awake surgery. Especially when surgery is performed under spontaneous respiration without an LMA, caution is required. In this case, end-tidal carbon dioxide is not so useful as described above, and it is difficult to determine whether changes of saturation of peripheral oxygen result from worsening of respiratory status or air embolism.[2,5] Upper airway obstruction causes lower negative intrathoracic pressure and may result in increased risk of air embolism. Although a bispectral index (BIS) monitor is generally considered to be useful, its value is limited and is not strongly recommended in the field of neurosurgical anesthesia. There have been reports that a BIS monitor is useful even if placed at sites other than the forehead. However, because shaving of the head recently tends to be minimized, the site where the monitor can be placed is actually limited to the forehead. Even if a pediatric BIS sensor is used, disinfectant or blood often enters the connections of the sensors and interferes with analysis. In addition, a BIS monitor is mainly useful on emergence, and its value before that is limited by contamination from electromyogram signals and noise from electric scalpels used during craniotomy.

Maintenance of the airway during awake craniotomy is done by one of two methods; one method is to depend on spontaneous respiration with no devices and the other method is to use a device such as the LMA. If a device is used, we can rely on spontaneous respiration and, if necessary, provide respiratory support, or we can actively perform ventilation. In Japan, the LMA has tended to be used recently. Tracheal intubation is not recommended since it is likely to interfere with an awake study because of complications caused by emergence-induced coughing and depressed laryngeal function including hoarseness. Although a tracheal tube can be placed in the pharynx via the nose for respiratory support, if necessary, or emergency intubation can be done with a bronchoscope, nasal bleeding can become a problem. If management is performed by spontaneous respiration without devices, hypercapnia will become a problem, but can often be dealt with by target controlled infusion, avoiding narcotics, or large craniotomy.[1,3,4] Partly to decrease the dose of narcotics, it is important to administer sufficient local anesthesia as described in the next section.

If 3-point fixation is performed, it is assumed that reinserting the LMA or tracheal intubation will be difficult in some cases. It is important to test removal and reinsertion of the LMA, to sufficiently discuss measures to tracheal intubation when the aggravation of the breathing state occurs during surgery. Also, when 3-point fixation is employed, check with the surgeons that the neck has not been twisted or anteflexed. As it is known that more problems related to the respiratory tract and respiration develop in patients with a body mass index >30, be careful about deciding to perform awake craniotomy in such patients.[6]

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### 5. Admission, induction, and local anesthesia

i) Initiate oxygen delivery after validation of the vital signs with a patient monitor.

ii) Induce anesthesia with only propofol, or in combination with fentanyl/remifentanil. A target-controlled infusion (TCI) system should be used for propofol administration to precisely manage the level of sedation. The administration of fentanyl before emergence should be minimal.

iii) Maintain general anesthesia under spontaneous respiration with a facemask, or under assisted/controlled ventilation after insertion of an LMA.

iv) Insert a urethral catheter.

v) Provide effective analgesia with local anesthetics by infiltration at the site of skin incision, and/or by selective nerve blocks of, for example, the supraorbital nerve and the greater occipital nerve. Ropivacaine is commonly used as a long-acting local anesthetic.

*[Commentary]*

Management of general anesthesia with inhalation anesthetics is ineffective when the airway is poorly established. The main impediments are uncertain delivery of the anesthetics and hazardous contamination of the operating room with the anesthetics. Propofol should be used as a hypnotic agent. Propofol is an intravenous anesthetic drug that permits faster and clearer emergence than inhalation anesthetics, which affect the electroencephalogram and sometimes induce excitement at emergence from anesthesia. A TCI system can reasonably be used for propofol in order to maintain an optimal hypnotic level by adjusting the effect-site concentration of the agent, as the sedative effect depends on the effect-site concentration. In the case of anesthetic management without the TCI system, the propofol administration should preferably be managed by continuous infusion combined with repetitive injection based on the effect-site concentration calculated with pharmacokinetic simulation. Opioids are sometimes used for sedation, but give some residual effects to the consciousness level after emergence. Remifentanil is therefore suitable in the management of strong surgical stimulation before emergence, as its effect rapidly disappears. It is also reasonable to administer small dose of fentanyl repeatedly, expecting only a slight residual analgesic effect.

The airway before emergence is usually managed with a facemask or an LMA. Airway management under assisted/controlled ventilation and spontaneous respiration can be performed safely with LMA, though it is generally difficult to extubate safely and smoothly at awakening. The incidence of muscle weakness in the conscious state is rare with LMA, as muscle relaxants are not necessary for LMA insertion. A nasogastric tube should not be inserted, as it leads to discomfort in the pharynx, nausea, and vomiting during the conscious state. Remove the nasogastric tube before emergence if it has to be inserted during general anesthesia. Insert a urethral catheter after induction of anesthesia, as the operation will take a long time.

The key to anesthetic management for awake craniotomy is to achieve a "pain-free" state with multimodal pain management. Since intravenous anesthetics affect the state of consciousness and respiration, local anesthetics are essential for assured analgesia. This is achieved with the use of long-acting local anesthetics such as ropivacaine or bupivacaine, or lidocaine combined with epinephrine. Problems such as local anesthetic toxicity did not occur even at a mean ropivacaine dose of 3.6 mg/kg in a study of the blood concentration of local anesthetics for awake craniotomy. Local anesthetics are administered by infiltration around pin fixation and the site of the skin incision, along with selective nerve blocks (supraorbital nerve, greater occipital nerve, etc.) Gauze soaked with local anesthetics can be pressed against the wound. Because direct contact of local anesthetics with the brain parenchyma causes central nervous system symptoms such as convulsions, the administration of local anesthetics after dural incision should be performed carefully.

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**6. Before emergence**

i) In principle, sedative and analgesic drugs should not be used during the awake time. Check the surgeons' preference for the level of consciousness (level of sedation).
ii) Discontinue propofol after the dural incision has been made. If sedation is to be continued, provide the required dose of propofol, etc.
iii) Closely monitor the patient because body movements may occur suddenly during the course of emergence.
iv) If an LMA and a gastric tube are used, confirm spontaneous respiration before removal.
v) If the patient exhibits restlessness and cannot keep still, intraoperative emergence may be abandoned after discussion with the surgeon and the procedure may instead be performed under standard general anesthesia.

*[Commentary]*

Because the tasks and tests used for brain functional mapping and electrocorticography to determine the extent of epileptic focus resection are generally susceptible to sedative and analgesic drugs, in principle, such drugs should not be administered during the awake time. Since even analgesics administered before emergence influence the extent of emergence, check the neurosurgeon's preference about the tests and sufficiently control the depth of anesthesia while considering the patient's preoperative condition. Poor emergence may make functional assessment difficult.[4]

During the period of strong surgical stimulation, including scalp incision, muscle detachment, and removal of the bone flap and dural incision, provide adequate sedation and analgesia, and discontinue propofol on completion of dural manipulation.[2] Body movement sometimes occurs during emergence as with other surgical anesthesia practice. Because sudden body movement can be more harmful when the skull is fixed with head pins and opened, sufficient vigilance is required and anesthesiologists should be prepared to control body movement. Anesthesiologists should promptly control major changes in circulatory and respiratory systems, which often occur during this period.[3] When a gastric tube or LMA is used, check spontaneous respiration and remove on emergence. Due to restlessness, the patient may not remain still and cooperate with functional tests.[1] If restlessness is considered to be caused by excitation, pain, poor posture, low temperature, residual anesthetic, or a painful urethral catheter, deal with the cause. If the cause is unknown or cannot be controlled, after discussion with the attending surgeon, intraoperative emergence may be abandoned and surgery may be discontinued or performed under general anesthesia.

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### 7. Awake period

i) In principle, systemic administration of sedatives and analgesics should not be done.
ii) For light sedation, administer propofol, etc. at the minimum required dose. (There are reports on the use of dexmedetomidine as a sedative. Use of remifentanil in patients with spontaneous respiration is not recommended because of respiratory depression.)
iii) If the patient complains of pain, provide additional local anesthesia first.
iv) If nausea and/or vomiting occur: Discontinue the surgical procedure, administer metoclopramide or a serotonin receptor antagonist, and wait for the subsidence of symptoms. Remove vomitus to prevent aspiration. If symptoms are severe and do not subside, consider sedation with propofol and discuss with the surgeons regarding the discontinuation of awake craniotomy.
v) If convulsions develop: Discontinue the surgical procedure, especially electrical stimulation. (If the electroencephalogram is being monitored, the operation should be discontinued when the first spike is seen.) Cool the brain surface with cold water. Administer propofol at a sleeping dose. Give an intravenous infusion of 250 mg of phenytoin. If convulsions do not cease even after additional administration of propofol, midazolam, or thiopental, discontinue awake craniotomy.

*[Commentary]*

During the awake period, as a general rule, systemic application of sedatives or analgesics should not be done in order to minimize the influence on functional mapping or the identification of epileptic foci. To deal with pain, add local anesthetics. If a small dose of a sedative or narcotic is considered to prevent worsening of the patient's mental state and excitation, the potential influence on functional assessment should be assessed. Recently, there have been several reports about anesthesia during awake surgery in which dexmedetomidine or remifentanil was used during the awake period.[1,3–6,9] However, there have also been reports that poor emergence of patients given dexmedetomidine required a decrease of the dose or discontinuation, and dexmedetomidine is not covered by health insurance in Japan. The use of remifentanil at low doses with spontaneous respiration on emergence has also been reported, but is not considered to be safe due to the potential for respiratory depression or brain swelling induced by hypercapnia, so this method would require careful attention.

Although the incidence of nausea and vomiting during awake surgery varies among reports, it has been reported to be approximately 0–10% when anesthetic management is primarily done with propofol.[8] Nausea and vomiting, in addition to causing discomfort for the patient, increases the risk of respiratory complications due to aspiration, and body movement and increased brain swelling associated with nausea/vomiting may make the surgical procedure more difficult. Nausea and vomiting may be induced by the surgical procedure or by use of narcotics. At the onset, immediately discontinue the surgical procedure and administer metoclopramide or a serotonin receptor antagonist. However, serotonin receptor antagonists are only available off label in Japan, requiring the decision to be made at each institution. If symptoms are severe and do not improve, consider sedation with propofol and even consider the discontinuation of awake craniotomy in certain cases. Although there are some reports about medications to prevent nausea and vomiting, the efficacy during awake surgery is unknown.

The incidence of convulsions during awake craniotomy depends on the underlying disease and is reported to be approximately 0–24%.[2,8] Convulsions are more likely to develop during electrical stimulation for brain functional mapping. If convulsions develop, discontinue electrical stimulation during the surgical procedure and cool the brain with cold Ringer's solution or saline. If the electroencephalogram is being monitored, discontinue the procedure at the onset of a spike. Most convulsions cease with discontinuation of the surgical procedure and cooling of the brain. If these measures are ineffective, administer propofol or phenytoin at a sleeping dose. The preventative effect of phenytoin has not been confirmed, so it is considered desirable to achieve an effective blood concentration before surgery. If convulsions do not cease with additional propofol, midazolam, or thiopental, discontinue awake craniotomy. There has been a report that intractable convulsions required general anesthesia with tracheal intubation.[7] During awake craniotomy, it is necessary to be prepared for emergency transition to airway management or general anesthesia at any time.


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### 8. Reinduction and completion of craniotomy

i) When the cooperation of the patient is not required any further, induce sedation with propofol.
ii) In principle, manage the patient with spontaneous respiration. However, if the airway needs to be secured because of oversedation, use the LMA. (Anesthesiologists who are experienced in handling the LMA may perform anesthetic management by deliberately using it at closure.)
iii) If needed, add more local anesthesia. However, if there is evidence of local anesthetic toxicity, discontinue additional anesthesia and provide necessary treatment such as establishment of an airway and countermeasures for convulsions.
iv) If the airway is established with an LMA, the required dose of fentanyl or remifentanil can be given for analgesia.

*[Commentary]*

Propofol is generally used as the anesthetic at the end of craniotomy, as it is during craniotomy.[1] Determine whether tumor resection will be performed in the awake state or under sedation with propofol, considering the conditions at each institution and each patient. Some surgeons want patients to be re-awakened after tumor resection to check for neurological symptoms.[1] Insertion of an LMA should be done via a lateral caudal approach and requires some degree of proficiency when the head is fixed with pins. There is a risk of difficulty with airway establishment or vomiting and is recommended for at least two anesthesiologists to be involved in inserting the LMA. After establishment of the airway with an LMA, management can be achieved by controlled respiration with remifentanil or fentanyl. If establishment of the airway takes a long time, tracheal intubation[2] can be considered. If establishment of the airway is not done, add further local anesthetic to continue surgery. Preparations should be made to allow for establishment of the airway with an LMA immediately after a sudden change of the patient's state, such as the onset of convulsions. If analgesia is insufficient, add a small dose of fentanyl. Caution is required with regard to the use of remifentanil with spontaneous respiration during craniotomy, as on emergence.


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**9. Emergence and discharge**

*i)* After the completion of surgery, discontinue sedatives and analgesics.

ii) Confirm emergence and the return of spontaneous respiration, remove the LMA if used, and transfer the patient to the intensive care unit.

*[Commentary]*

Follow the regular procedures for neurosurgical anesthetic management of emergence and discharge.

## III. LANGUAGE ASSESSMENT DURING AWAKE CRANIOTOMY

**1. Methods of language mapping by cortical electrical stimulation during awake craniotomy**

*[Recommendation]*

*Indications*: Patients with lesions around the perisylvian language areas of the dominant hemisphere. Patients without apparent aphasia who are able to fully understand the language tasks and cooperate with them.

*Preoperative preparation*: Set language tasks that can easily be performed by patients and fully familiarize them with the tasks.

*Electrical stimulation*: A stronger stimulus intensity (6–12 mA) and longer duration (2–4 sec) are required than for motor and sensory mapping. Initiate electrical stimulation immediately before presenting the language stimulus (line drawing or question) and continue it during presentation.

*Language tasks*: Perform counting, visual naming, and listening comprehension tasks for cortical mapping. If electrical stimulation reveals any dysfunction, assess reproducibility. Monitor language functions primarily on the basis of spontaneous speech during resection. If an abnormality is suspected, perform language mapping with visual naming and/or listening comprehension.

*[Commentary]*

Purpose: The purpose of language mapping is to identify the language areas and to avoid postoperative aphasia by preserving these areas. Because the extent of the language areas varies among individuals and it is difficult to accurately identify them anatomically, the areas should be determined for each individual.[5] If language areas are identified outside the resection zone and language functions are confirmed to be localized away from the lesion to be resected, the neurosurgeon can resect the lesion with confidence.

*Indications*: Because patients must have full understanding and good cooperation to perform language mapping, we should consider the preoperative cognitive level and mental maturity of the patient. Because some patients cannot adapt to the special circumstances of the operating room environment, after providing sufficient explanation and practice of the tasks, determine whether they are suitable candidates for awake surgery or not. Be especially careful with young and elderly persons. Children and patients with obvious aphasia before surgery are not suitable for language mapping. Patients showing slight anomia or word finding difficulty (poor word production by category or initial phonemes) during preoperative examination may attempt language mapping, but their language function can become worse than preoperatively because of drowsiness, which can make language mapping difficult.

*Preoperative preparation*: Examination: Perform neurological and neuropsychological testing. Explanation: Fully explain the language tasks that will be used for mapping. Establishment of tasks: After performing the standard tasks once, exclude stimuli that evoke unstable responses, leaving only the stimuli for which the patient can definitely provide correct answers. Determine the rate of presenting line drawings at which the patient can answer comfortably (2–5 sec intervals). Practice: The selected tasks should be practiced several times until the patient can answer with confidence. If examination reveals suspected decrease of language function, perform the standard aphasia tests to measure the severity of aphasia. Identification of language-related sites by fMRI might be useful to limit the area that has to be explored by intraoperative mapping.[8]

*Electrical stimulation*: Follow the usual standards, but remember that stronger and longer stimulation is required for language mapping. Employ a stimulus intensity of 6–12 mA if no afterdischarge is evoked. Because electrical stimulation is initiated immediately before presenting a line drawing or question and is continued during presentation, stimulation needs to be applied for between 3 and 4 seconds (Fig. 5). It is desirable to present the language tasks at regular intervals so that the neurosurgeons get used to the timing of electrical stimulation. Also, adjust the location of the screen so the surgeons are able to monitor stimulation during the language tasks.

*Language tasks*: Language tasks to be performed: For all areas to be tested, counting and visual nam-

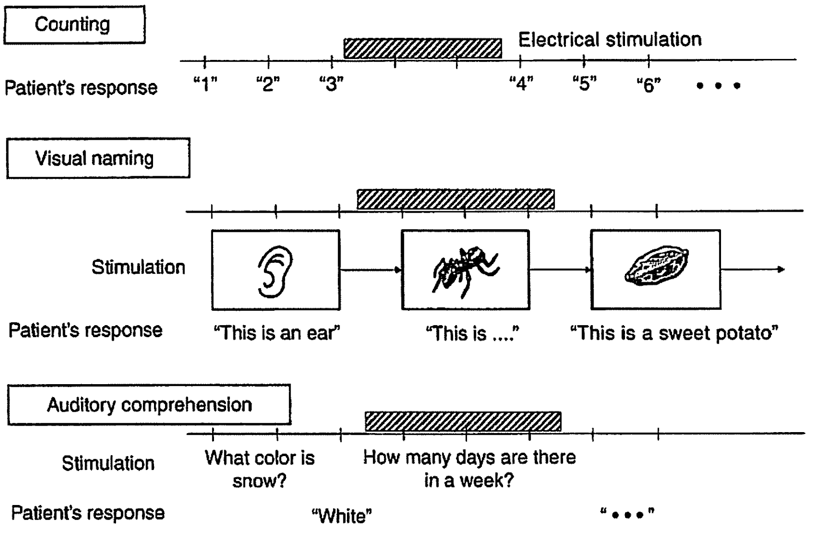


**Fig. 5 Flow chart of language tasks. Initiate electrical stimulation before presenting the language tasks.**

ing should be performed. With counting, check speech arrest and delay. Confirm that the site of speech arrest does not correspond to the negative motor area. During the visual naming task (picture naming), record slips of the tongue (errors), delayed responses, or no response. Words for the naming task are selected from among high-frequency words, such as cat, knife, desk etc. For the temporal lobe, also perform auditory comprehension. Frequency: Stimulate each site twice or more with the maximum current to check whether a language abnormality is detected. If any language abnormality is detected, stimulate the site twice or more again to check reproducibility. Interpretation of results: If three stimuli induce at least two incorrect responses, the site should be designated as a language-related site (Fig. 5).

*Cortical mapping*: Counting (from 1 to 30): Perform electrical stimulation while asking the patient to count from 1 to 30 at approximately one number per second. After the patient reaches 30, he/she starts from 1 again. Identify the sites where stimulation leads to abnormalities of speech (arrest, delay, dysarthria). Regarding the sites associated with these abnormalities, ask about the patient's subjective symptoms (e.g., inability to move the tongue). Then, assess whether or not the sites are primary motor areas or negative motor areas related to articulation. Visual naming[7]: Present line drawings (on paper or a monitor) at the interval predetermined for each patient and instruct the patient to name them using a carrier phrase like "This is...". Anomia or paraphasia: After saying "This is" fluently, patients cannot recall the name or substitute one word for another. Speech arrest: The patient cannot say "This is". Auditory comprehension: The patient answers an easy question with a single word. Because this involves both word recall and listening comprehension, electrical stimulation at sites different from those related to visual naming induces abnormalities.[3] Language mapping is based on the above three tasks. If time permits, other language tasks can be added as required.

*Subcortical mapping*: This is required if nerve fibers immediately below or adjacent to the language areas are to be resected. Continue conversation between the patient and examiner during resection and perform mapping with electrical stimulation at the sites with possible abnormalities. Use visual naming and, for the posterior language areas, listening comprehension as well. The intensity of electrical stimulation should be equal to or slightly greater than that for cortical stimulation. Identification of nerve fascicles by preoperative tractography might be useful to determine the sites for subcortical mapping.[1,2,4]

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**Table 1 Examples of line drawings used in the visual naming task**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Grape | Ear | Ant | Potato | Train | Strawberry | Eye | Cat | Truck | Rabbit |
| Bus | Scissors | Patrol car | Carrot | Plane | Chicken | Pencil | Motorcycle | Apple | Cup |

Words are selected from among high-frequency words in the vocabulary test for aphasia and color drawings without copyright are used.

46: 927–934, 2008

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## 2. Task details

Examples of line drawings used in the visual naming task and questions used to treat auditory comprehension are shown in Tables 1 and 2, respectively.

**Table 2 Examples of questions used to test auditory comprehension**

1. What is your name?
2. What color is snow?
3. What color is a sunflower?
4. What color is a crow?
5. What color is a banana?
6. What color is a fire truck?
7. How many days are there in a week?
8. How many minutes are there in an hour?
9. How many legs has a dog?
10. What day is after Tuesday?
11. What season is after spring?
12. What month is New Year's Day in?
13. What month is the Bon Festival in?
14. Which direction the sun sets in?
15. What is the offspring of a frog called?
16. What is the offspring of a chicken called?
17. A mother is a woman. What is a father?
18. A brother is a man. What is a sister?
19. The sun shines during the daytime. When do the stars come out?
20. Cherry blossom is seen in spring. How about red leaves?
21. Where do you buy postage stamps?
22. What do you use to cut vegetables?
23. What do you use to cut paper?
24. What do you use to tell the time?
25. Hot water is hot. How about ice?
26. Iron is heavy. How about feathers?
27. The sea is deep. How about mountains?
28. You wear clothes. How about shoes?
29. Birds fly. How about fish?
30. You listen to music. How about paintings?

Questions that can be answered within approximately 2 seconds are prepared based on the Wechsler Intelligence Scale for Children-Revised, Illinois Test of Psycholinguistic Abilities, Western Aphasia Battery test, etc.

## Appendix: GUIDELINES COMMITTEE OF THE JAPAN AWAKE SURGERY CONFERENCE

**Chairman of the Committee**

| | |
|---|---|
| Takamasa KAYAMA | (National Cancer Center & Dept. of Neurosurgery, Yamagata University Faculty of Medicine) |

**Co-Chairman of the Committee**

| | |
|---|---|
| Hiroshi ISEKI | (Tokyo Women's Medical University, Faculty of Advanced Techno-Surgery) |
| Yoshitsugu YAMADA | (Dept. of Anesthesiology, Faculty of Vital Care Medicine, The Graduate School of Medicine, The University of Tokyo) |

**Committee Members**

| | |
|---|---|
| Tatsuya ABE | (Dept. of Neurosurgery, Oita University Faculty of Medicine) |
| Chikashi FUKAYA | (Dept. of Neurosurgery and Applied System Neuroscience, Nihon University School of Medicine) |
| Hidekatsu FURUTANI | (Dept. of Anesthesia, Kyoto University Hospital) |
| Kazuhiro HONGO | (Dept. of Neurosurgery, Shinshu University School of Medicine) |
| Tohru ITAKURA | (Wakayama Medical University) |
| Koji KAJIWARA | (Dept. of Neurosurgery, Yamaguchi University Graduate School of Medicine) |
| Kyosuke KAMADA | (Dept. of Neurosurgery, Asahikawa Medical University) |
| Masahiko KAWAGUCHI | (Dept. of Anesthesiology, Nara Medical University) |
| Mikito KAWAMATA | (Dept. of Anesthesiology and Resuscitology, Shinshu University School of Medicine) |
| Toshihiro KUMABE | (Dept. of Neurosurgery, Tohoku University Graduate School of Medicine) |
| Junichi KURATSU | (Dept. of Neurosurgery, Kumamoto University School of Medicine) |
| Masanori KURIMOTO | (Dept. of Neurosurgery, University of Toyama, Faculty of Medicine) |
| Nobuhiro MIKUNI | (Dept. of Neurosurgery, Sapporo Medical University, School of Medicine) |
| Yasuhiro MORIMOTO | (Dept. of Anesthesiology, Yamaguchi University Graduate School of Medicine) |
| Yoshihiro MURAGAKI | (Tokyo Women's Medical University, Faculty of Advanced Techno-Surgery) |
| Osamu NAGATA | (Dept. of Anesthesiology, Tokyo Women's Medical University) |
| Kaori SAKURADA | (Dept. of Neurosurgery, Yamagata University Faculty of Medicine) |
| Kiyotaka SATO | (Dept. of Anesthesiology, Kohnan Hospital) |
| Shinya SATO | (Dept. of Neurosurgery, Yamagata University Faculty of Medicine) |
| Nobusada SHINOURA | (Dept. of Neurosurgery, Komagome Metropolitan Hospital) |
| Morihiro SUGISHITA | (Institute of Brain Vessels) |
| Masahiko SUMITANI | (Dept. of Anesthesiology and Pain Relief Center, The University of Tokyo) |
| Kyoko SUZUKI | (Dept. of Clinical Neuroscience, Yamagata University Faculty of Medicine) |
| Seiji TAKAOKA | (Dept. of Anesthesiology, Yamagata City Hospital Saiseikan) |

CASE REPORT

Neurol Med Chir (Tokyo) 52, 439～442, 2012

# Ruptured Aneurysm With Delayed Distal Coil Migration Requiring Surgical Treatment

## —Case Report—

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**Abstract**

**A 64-year-old woman with subarachnoid hemorrhage manifesting as sudden onset of severe headache visited our hospital on post-onset day 8. Diagnostic cerebral digital subtraction angiography revealed an aneurysm located at the left internal carotid-anterior choroidal artery with diffuse cerebral arterial spasm. Coil embolization was selected because of diffuse spasm in spite of parent artery elongation at the extra-cranial portion. A small portion of the coil migrated to the parent artery, but coil embolization was successfully completed. The patient developed delayed spasm, which required arterial fasudil hydrochloride injection. After the acute phase of subarachnoid hemorrhage, the patient's symptoms disappeared. However, on day 24 after subarachnoid hemorrhage, the patient showed right hemiparesis and total aphasia, and skull radiography revealed that the migrated coil had moved into the M1 portion of the left middle cerebral artery. Craniotomy was performed to retrieve the coil and clip the aneurysm neck. However, the migrated coil could not be retrieved because of adhesion to the arterial wall. Delayed coil migration is very rare in the chronic phase.**

Key words: subarachnoid hemorrhage, coil embolization, delayed coil migration, clipping, complication

## Introduction

The International Subarachnoid Aneurysm Trial (ISAT) is the only multi-center prospective randomized clinical trial, considered the gold-standard in study design, comparing surgical clipping and endovascular coiling of ruptured aneurysm. The ISAT found that patients equally suited for both treatment options achieved substantially better outcomes after endovascular coiling treatment than after surgery in terms of survival-free disability at one year. However, the coiling technique is technically developing and continues to carry risks of unexpected complications. Coil migration is one of the rare complications, but might be related to poor functional outcome. Therefore, evaluation techniques such as volume embolization ratio (VER) and new embolization devices have been developed to improve aneurysm stability after endovascular treatment with platinum coils.

We describe a case of bizarre coil migration in a patient with a ruptured internal carotid-anterior choroidal artery aneurysm treated by surgical excision of the migrated part for rescue treatment.

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## Case Report

A 64-year-old woman visited the emergency service of Nayoro City Hospital because of severe headache persisting for a week. She had suffered sudden onset of headache and nausea for 8 days. Head computed tomography (CT) demonstrated residual clot in the subarachnoid space (Fig. 1A, B; Fisher group 3), and the diagnosis was subarachnoid hemorrhage (SAH) on the 8th day after occurrence (Hunt and Kosnik grade 2). Emergent angiography revealed an aneurysm at the left internal carotid-anterior choroidal artery (4.5 × 5.4 × 3.2 mm, neck: 3.9 mm) with severe intracranial arterial vasospasm (Fig. 1C). In addition, the internal carotid artery (ICA) in the cervical portion was tortuous and had a loop, which suggested difficulty in accessing the aneurysm by the endovascular approach (Fig. 1D). However, considering the vessel structure anomaly and vasospasm, we selected aneurysm embolization by endovascular coils.

Under general anesthesia, a Slimguide catheter (6 Fr; Medikit, Tokyo) with a 6-Fr sheath was inserted via the right femoral artery and positioned at the proximal portion of the cervical ICA. An Excelsior SL-10® 45 preshaped microcatheter (Stryker Neurovascular, Fremont, California, USA) was carefully navigated to the aneurysm using a Synchro² Soft 0.014 micro guidewire (Stryker Neu-

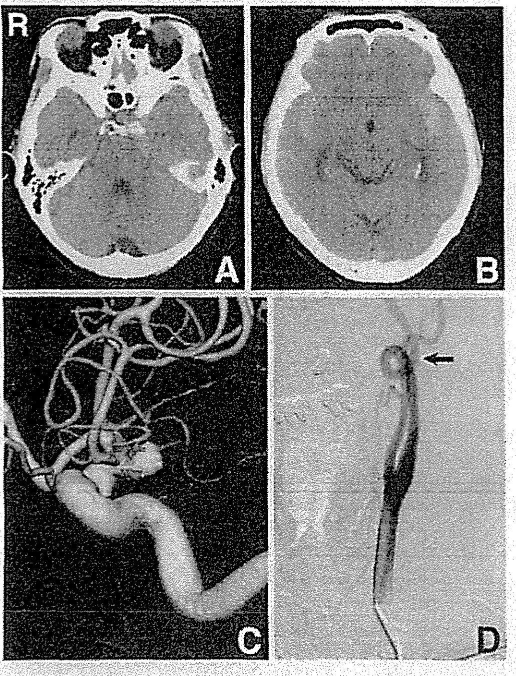


Fig. 1 A, B: Computed tomography scans on admission showing subarachnoid hemorrhage. C: Three-dimensional digital subtraction angiogram revealing an anterior choroidal artery aneurysm. D: Left common carotid angiogram showing coiling of the extracranial internal carotid artery (arrow).

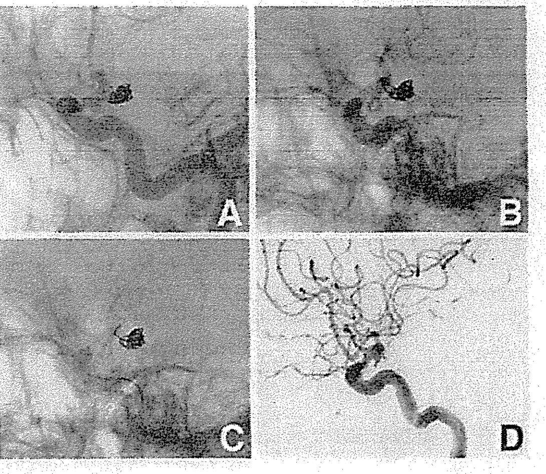


Fig. 2 A–C: Left internal carotid angiograms, lateral view, showing placing the 3rd coil into the aneurysm (A), but a loop protruded into the left internal carotid artery (B). The loop was unraveled and moved into the left internal carotid artery (C). Then, we abandoned detaching the fourth coil. D: Post-coil embolization subtraction image showing only a small neck remnant, so we decided that this operation should be abandoned.

rovascular). For the first coiling, a cage formation was created inside the aneurysm using DCS complex fill 5 × 5 (Cordis Corporation, Bridgewater, New Jersey, USA) (Fig. 2). After successful cage formation, flexible platinum coils were introduced such as DCS mini-complex fill 3 × 4 coils to fill the inner cavity of the aneurysm, and moderate aneurysm packing was confirmed. After intravenous administration of 3,000 units of heparin, GDC UltraSoft 3 × 4 coils (Stryker Neurovascular) were inserted for complete embolization. The last coil was too soft and redundant, resulting in a loop which protruded into the parent artery and pushed the microcatheter away from the aneurysm. Although we tried to achieve complete packing using a shorter coil (GDC UltraSoft 2 × 2), the aneurysm neck was too wide to hold the looped coil, and coil manipulation was severely disturbed by the cervical ICA anomaly. We abandoned further procedures because blocking of the blood flow into the aneurysm had been completed, and we planned to observe the remaining coil loop. The total coil length was 9 cm, and the VER was 17.4%.

After the endovascular treatment, the patient had no neurological deficit. Cerebrospinal fluid was continuously drained with intrathecal administration of urokinase (6,000 units/day) and aspirin (100 mg/day) was orally administered to prevent deterioration of vasospasm. Two days later (10th day after onset), she suffered right hemiparesis and aphasia, and emergent cerebral angiography disclosed narrowing of the bilateral anterior cerebral arteries and middle cerebral arteries (MCAs) (Fig. 3A). Severe vasospasm was considered to be the cause of the symptoms and 30 mg of fasudil hydrochloride was administered via the 4-Fr angiographic catheter. No displacement or migration of the coils in the aneurysm and improvement of vasospasm were confirmed. The symptoms persisted until the 12th day and head CT revealed a low density area in the left frontal region (Fig. 3B, C). Cerebral angiography was repeated and 30 mg of fasudil hydrochloride injected into the left ICA for symptomatic vasospasm. The coil shape including the protrusion maintained stable. After the 3rd angiography, she gradually

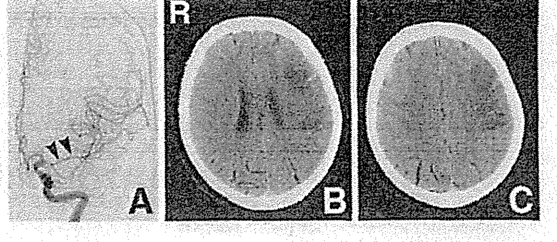


Fig. 3 A: Left carotid angiogram, anteroposterior view, before arterial injection of 30 mg of fasudil hydrochloride on day 10 revealing delayed arterial spasm (arrowheads). B, C: Computed tomography scans on day 10 showing low density areas in the left frontal lobe.

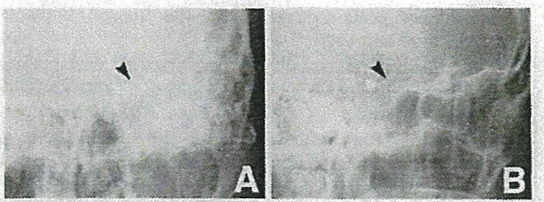


**Fig. 4** Skull radiographs, Town's (A) and lateral views (B), on day 24 showing the migrated coil portion (*arrowhead*).

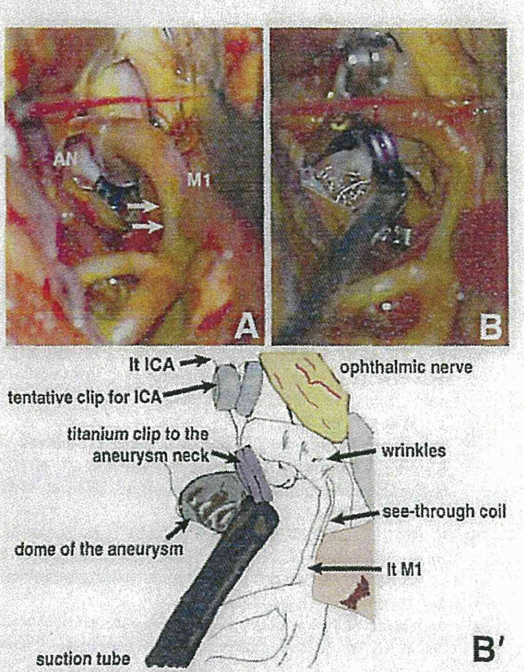


**Fig. 5** Intraoperative photographs. A: After opening the left sylvian fissure, the migrated coil was seen through the middle cerebral arterial wall (*arrows*). AN: aneurysm dome, M1: M1 portion of left middle cerebral artery. B: A clip was applied to the neck of the aneurysm, and the cut anterior aneurysm wall and coils were seen. The clip head was opened slightly, to try to retrieve the migrated coil. However, the coil was adhered to the arterial wall. When the coil was pulled, a wrinkle was caused on the wall of the M1 artery. The coil could not be removed. B': Illustration of B. ICA: internal carotid artery.

recovered from the symptoms. In the early morning of the 24th day after onset, severe right hemiparesis and total aphasia suddenly appeared. Emergent magnetic resonance (MR) imaging demonstrated no new lesion on diffusion-weighted images except for old ischemic changes due to the vasospasm. MR angiography showed uncertain signal loss between the peripheral portion of the left ICA and the proximal site of the MCA. Radiography depicted part of the embolization coils was stretched and

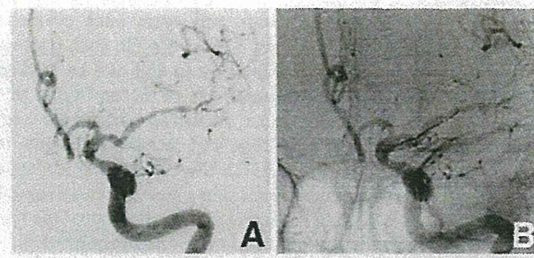


**Fig. 6** Left internal carotid angiograms, anteroposterior view, showing no aneurysm in the digital subtraction image (A), and the remaining coil and clips (B).

had migrated from the aneurysm neck to the MCA (Fig. 4). Although the symptoms diminished within 6 hours without special treatment, we decided to retrieve the migrated part of the coils by open surgery, to avoid embolic events or arterial wall injury and aneurysm re-rupture.

The left ICA and the aneurysm were exposed by left fronto-temporal craniotomy and part of the migrated coil was observed between the ICA top and proximal MCA (Fig. 5). After temporary clips were placed at the proximal and distal sites of the aneurysm on the ICA, the translucent aneurysm sac was opened for complete removal of the coils. However, the entire coil was impossible to withdraw because of severe adhesion between the migrated part and the MCA arterial wall. As the coil was pulled, a wrinkle was caused on the wall of the M1 artery. Therefore, we removed only the coils in the aneurysm, preventing further coil migration, since aggressive manipulation might worsen arterial wall injury. Aneurysm clipping was achieved with 2 titanium clips (Yasargil 720T; Aesculap AG, Tuttlingen, Germany) and the coil remnant was cut at the aneurysm neck inlet, leaving the migrated part in the M1. Postoperative angiography demonstrated 8 mm of the remnant coil remained between the ICA top and proximal MCA with complete aneurysm clipping (Fig. 6). Six months after the open surgery, she had suffered no new neurological deficit, and the remnant coil had not migrated or caused any new ischemic event.

## Discussion

The present case of SAH caused by a ruptured aneurysm and associated with severe vasospasm initially treated with endovascular embolization. Although serial angiography showed no deformity or dislocation of the coils during the acute period, coil migration was found more than 3 weeks after the embolization. The superiority of coil embolization over clipping for ruptured aneurysms within 2 years after onset has been proposed. In particular, the endovascular procedure causes fewer ischemic complications during the vasospasm phase in patients with SAH.[1,7] In this case, coil embolization was appropriate to avoid re-bleeding in the acute period.

In general, migration of the coil outside the aneurysm is caused by stopping packing while the coil partially pro-