

Awake craniotomy for the sensorimotor tumors : combined use of synthesized surface anatomy scanning, stimulation cortical mapping and frameless neuronavigation system

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Abstract

Objectives: Functional brain mapping and precise localization are essential for the resection of centrally located tumors. We describe our initial experience with awake craniotomy for sensorimotor tumors in 15 patients using synthesized surface anatomy scanning (SSAS), intraoperative functional brain mapping, and an infrared-based navigation system (INS) without fixation of the patient's head.

Methods: Craniotomy positioning was planned using the images created by SSAS. Fiducial markers were placed along the skin incision line for intraoperative registration of an INS. The resection of the tumor was performed under local anesthesia using both intraoperative functional brain mapping and an INS. In or near the motor cortex or the descending motor pathway, the extent of the resection was determined by the stimulation induced motor response and the intraoperative neurologic findings.

Results: Appropriately centered craniotomies were obtained in all cases using the presurgical planning images of SSAS. Reliable functional localization was identified with direct cortical and subcortical stimulation. The location of the tumors was detected within 3.5 mm of that predicted by the computation (target registration error). Postoperative computed tomography scans showed grossly total resection of the tumor in 13 of 15 cases and subtotal resection in 2 cases. Although 10 patients had mild to severe neurologic deficits in the immediate postoperative period, there were no permanent deficits.

Conclusions: Sensorimotor tumors can be resected effectively with the combined use of SSAS, stimulation cortical mapping and an INS with clinical acceptable morbidity.

Keywords: awake craniotomy, functional brain mapping, neuronavigation system, eloquent area, brain neoplasm

Introduction

Precise anatomic and functional localization are essential for the resection of central brain tumors. Intraoperative stimulation mapping is useful to detect the functional localization of the cerebral cortex. Neuronavigation system was developed to detect the brain lesion in 'real time' during the surgery. Several institutes reported the surgery of the eloquent area with the combined use of intraoperative stimulation cortical mapping and neuronavigation system.^{1,2}

Katada³ has previously described the surface anatomy scanning (SAS) technique utilizing T2 weighted magnetic resonance imaging (MRI). A major limitation of this method is its inability to detect lesions with only a mildly prolonged T2 or with surrounding edema. To overcome these problems we introduced combining synthesized SAS (SSAS) with contrast-enhanced MR angiography (CMRA) (with projection of the CMRA data on SAS).⁴ SSAS can display all brain structures including the gyri, sulci, superior sagittal sinus, and superficial cerebral veins. It can also discriminate subcortically enhanced

lesions from surrounding edema and can image skin markings for craniotomy. With the use of SSAS images, preoperative planning can be carried out.

The anatomic landmarks used to localize the eloquent cortical regions can be imprecise. Studies by Burchiel et al⁵ demonstrated variability in the location of both the motor and the language cortex. Congenital cortical lesions, such as arteriovenous malformations, may additionally alter location by displacing one functional area to another.⁶ Therefore, for lesions around or in the eloquent cortex, functional mapping must be performed.

Stimulation mapping of the mammalian cerebral cortex is not a new concept and been used by Fritsch and Hitzig,⁷ Grunbaum and Sherrington⁸ and Ferrier.⁹ This work largely confirmed the hypothesis of Jackson¹⁰ and others that a distinct anatomic region known as the primary sensorimotor cortex existed and was responsible for contralateral movements of the extremities and trunk following neuronal excitation. Cushing¹¹ and Foester¹⁰ subsequently applied the technique of direct cortical stimulation during operative exposure of the human cortex and separated the Rolandic cortex into two distinct regions; for example, the precentral (motor) and postcentral (sensory) gyri. In 1937, Penfield and Boldrey¹² described in detail their results of electrical stimulation mapping of the cortex in 163 patients undergoing surgery with local anesthesia to treat epilepsy and

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tumors. Later, intraoperative functional brain mapping became popular for the surgical approach to a variety of lesions in the eloquent area, including tumors.¹³⁻¹⁹ The motor strip may be identified in the awake or asleep patient using currents between 2 mA and 16 mA, depending upon the anesthetic condition of the patient.²⁰ The same current that identifies the cortical site of neuronal origin for both motor and sensory function is also able to depolarize the axonal tracts in the subcortical white matter.²⁰

The limited ability to map the functional territories of the brain intraoperatively, especially on the intact surface of the cerebral cortex, is still a basic problem in neurosurgery. There are no visual landmarks to use as guides. As a result, the idea of frameless localization was born. The realization of this neuronavigational concept led to graphic interactive neurosurgery.

In this report, the question of whether use of awake craniotomy neuronavigation combined with functional mapping contributes to a better clinical outcome in patients who undergo surgery in the area around the sensorimotor cortex is answered.

Patients and Methods

Patients

Fifteen patients underwent resection tumors in the sensorimotor region between April 1999, and June 2001 (Table). There were 3 women and 12 men in the group who ranged in age from 17 to 84 years (mean 51.1 years). These cases included a variety of cerebral lesions: metastatic tumor (n=7), glioma (n=6), cavernoma (n=1), and abscess (n=1). Clinical presentations included seizure (n=5), headache (n=3), and hemiparesis (n=7). Preoperatively, motor and sensory cortices were identified by computed tomography (CT) and MRI. The aim of microsurgery was total resection of the lesions with minimal damage to the motor cortex. Each patient's neurologic function was evaluated before, during, and after surgery.

Synthesized Surface Anatomy Scanning (SSAS)

The position of the lesions was predicted using CT, MRI, and contrast enhanced MR angiography (CMRA); the predicted position of the lesion and craniotomy were marked on the patient's scalp. Tubes filled with water were then placed on the marking.

MRI scans were obtained using a Shimazu SMT-150 with a superconductive magnet. SAS data were obtained using the pulse sequence for steady-state free precession (SSFP). The standard scanning parameters for SAS were TR/TE=40/50, flip angle (FA)=60 and two excitations. CMRA was obtained using a 2D-TOF technique with injection of gadolinium-DTPA (Gd-DTPA). The parameters for CMRA were TR/TE=100/12, FA=80 to 120 and one excitation. The slab for SAS and CMRA contained 7 to 14 min. Multi-step tilted stereograms of SAS and CMRA were reconstructed with a maximum intensity projection (MIP) algorithm, and then the two were superimposed.⁴

The position of the skin markings (for the skin incisions) was further corrected to surround the tumor using the SSAS image. Next, 10 fiducial markers were placed along the skin incision lines (Fig. 1). All patients then underwent a preoperative contrast-enhanced CT or gadolinium enhanced MRI scan with the fiducial markers as the points of reference. These images were then transferred to a database and registered for surgical planning.

Anesthesia and Intraoperative Functional Brain Mapping

Prior to each operation, the surgeon first explained to the patient the options for treatment and then obtained informed consent for the procedure. Two to 3 hours preoperatively, local anesthetic blocks of the greater occipital nerve, lesser occipital nerve, auriculotemporal nerve, and supraorbital nerve were performed using approximately total amount of 12 ml of 0.5% bupivacaine with epinephrine 1:200,000.⁶

Patients operated on while awake were brought to the operating room and placed in a semilateral position with a soft pillow or doughnut under the head. Great efforts were made to ensure patient comfort so that the patient could remain in one position for the duration of the procedure. Before sedation with propofol, a nasal endotracheal tube (Rush) was placed as a nasal airway in the pharyngeal cavity so that an endotracheal intubation could be immediately performed by using fiberoptic or nasogastric tube if needed.^{21,22} A microphone was placed beside the patient so that the patient could converse with the surgeon intraoperatively. Subdermal needle electrodes were inserted into 12 to 16 muscles to provide broad coverage of the appropriate body regions or an electromyogram (EMG). The surgical drapes were placed so as not to block the visibility of the fiducial markers on the skin. Before the craniotomy, 50 ml of local anesthetic (a 1:1 mixture of 0.5% lidocaine with epinephrine 1:100,000 and 0.25% bupivacaine) was used to infiltrate the proposed craniotomy scalp flap.⁵ Skin incisions were made and a craniotomy was performed. After the bone was removed, the propofol was discontinued. Once the patient awakened, intra-operative functional brain mapping and the resection of the tumor were carried out.

A current generator (Nihon Koden, Tokyo, Japan) produces a train of biphasic square wave pulses with a frequency of 60 Hz and a single phase duration of 1.25 msec. The current is delivered via a bipolar stimulator with the carbon-tips spread 5 mm apart. Intraoperatively the patient's motor strip was stimulated with a starting current of 1 mA and then with increases in 1 mA increments until a motor response was identified.

During the cortical mapping, eight channels of EMG response were recorded using a Nicolet Viking IV system (Nicolet Biomedical, Madison, WI).²³ It was equipped with a display monitor and a speaker for the EMG signal and an acoustic alarm, respectively. The motor response was recognized not only by visual observation of elicited overt movements, but also by EMG recording.²³

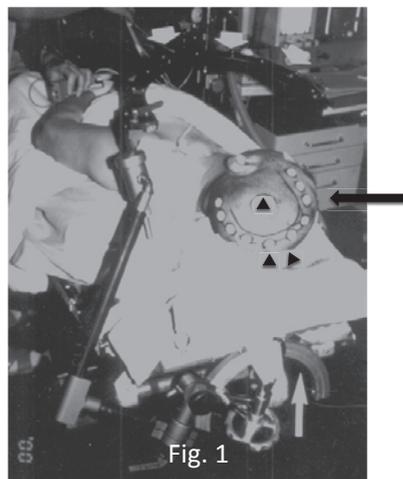
Closure of the craniotomy was performed with propofol sedation.

Neuronavigation System

Intraoperatively, an infrared-based system was used in all patients to confirm the localization and the extent of the resection in real time as described previously.²⁴⁻²⁶ In brief, continuous localization was achieved using the Flash Point Model 5000 tracking device (Image Guided Technologies, Boulder, CO) along with the Stealth-Station (Stealth Technologies, Boulder, CO). It consisted of a three charge-coupled device (CCD) camera, a reference frame, and a localizer probe. Both the reference arc and the probe are equipped with light emitting diodes (LED). The CCD cameras measure the location of the LED, which are then processed into three-dimensional (3D) coordinates which are down loaded into a graphics workstation (SGI Indigo, Silicon Graphics, Mountain

View, CA), where the position of probe tip is displayed as it corresponds to the image data. Generally, the reference arch is fixed to the head holder, however in our procedure, as the patient's head was not fixed with a head holder, the reference frame was fixed to the bed and the fiducial markers were placed on the scalp along the incision line for the registration (Fig. 1).

Figure 1



The patient is placed in a semilateral position with a soft pillow. Ten fiducial markers are located on the scalp along the proposed skin incision line (arrow heads). The reference frame (arrows) is fixed to the Sugita's head frame (an arrow), which is rigidly fixed to the bed. An arrow head indicate the position of the lesion predicted by SSAS image.

The surgical procedure started with registering or mapping the image studies within the operative field (intraoperative registration). This is achieved by touching the pointer (probe) on ten "real" points, which are fiducial markers on the scalp that can be easily located on the precaptured images. After this, whenever the pointer is used, its tip position and trajectory are simultaneously displayed as a computer image, giving real-time orientation. During these procedures, it is important for the patient to lie still. But if the patient's head does move during or after the registration, the surgeon can register again since the fiducial markers are always in the visual field.

Surgery

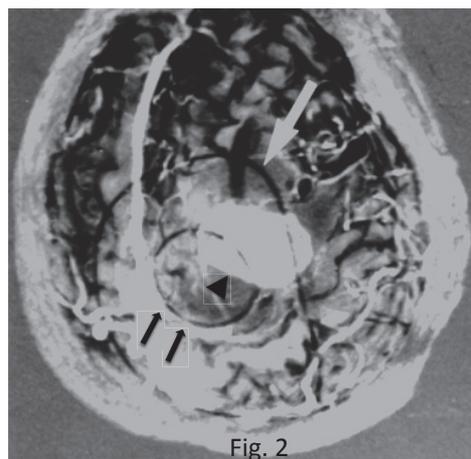
The central and precentral sulcus were separated to expose the tumor. The tumors were then resected so as not to injure the normal cortex. The extent of the resection was determined by cortical and subcortical stimulation^{23,27,28} and intraoperative neurologic findings. It took from 4 to 7 h to carry out the entire procedure. No patients complained of pain. All operations were performed by the same surgeon at single institution.

Results

SSAS displayed the relationship between the tumor and brain surface structures and skin markings. Skin incision line was planned by correctly positioning the skin markings to surround the lesion according to SSAS images (Fig. 2). With the use of SSAS, correctly centered craniotomies were performed in all cases.

Functional brain mapping was obtained in all cases using direct cortical stimulation under local anesthesia. EMG monitoring enhanced the ability to detect the location of the

Figure 2



Synthesized surface anatomy scanning (SSAS). SSAS demonstrates cortical sulci, superior sagittal sinus, superficial cerebral vein, gadolinium-enhanced tumor (an arrow head), and the skin marking on the scalp. An arrow and arrows indicate the position of craniotomy and the lesion predicted by CT or MRI before SSAS respectively. According to this image, the skin marking for the craniotomy was corrected to surround the tumor.

primary motor cortex and subcortical pathways with electrical stimulation.

Although the patient's head was not fixed with a head holder, the patients all cooperated. During the registration and localization, patients did not move. Stealth Station localized the tumor within 3.5 mm of its margin. The margins of the subcortical lesions on the brain surface were marked with surface letters.

Thirteen of fifteen patients were kept awake during the resection of the tumor. In 2 patients (Fig. 3), severe brain swelling occurred during closure of the craniotomy with propofol sedation after resection of the tumor. Arterial blood gas data indicated that the patient retained carbon dioxide, so the nasal endotracheal Rush tube, placed in the pharynx as an airway, was advanced into the trachea through the nasogastric tube which had been inserted first into the trachea through the inside of the Rush tube in the pharynx.^{7,8} Ventilation was then controlled mechanically and the patient was hyperventilated. In one patient, brain swelling resolved within 10 min because endotracheal Rush tube placed in the pharynx could be advanced immediately into the trachea and he had no neurological deficit postoperatively, while in another case intratracheal intubation could not be performed smoothly and the patient had transient hemiparesis owing to the compression of the brain caused by bone edge of the craniotomy during the brain swelling. Two of fifteen patients were sedated with propofol after the functional brain mapping because the patients hoped to have sedation during resection of the tumor.

The clinical features of each patient and the location of the tumor are outlined in Table.

In 13 cases, the extent of the resection was determined according to the stimulation evoked motor response. On the other hand, in 2 cases, the border of the resection was determined by the patient's neurologic findings during the surgery. In these cases, as the resection produced complete paresis of their limbs, resection was halted, despite the fact that cortical stimulation or subcortical stimulation induce motor responses at that time.

Postoperatively, transient worsening of neurologic deficits

Table Summary of the cases

case	sex	age	location	presentation	Neurological findings		pathology	radiological findings
					P.O.D.1	P.O.D.14		
1	M	62	Motor cortex	Mild Hemiparesis	worsen	No deficit	Adenocarcinoma	total resection
2	M	17	Corona radiata	Headache	Sensory deficit	No deficit	Sarcoma	total resection
3	M	57	Premotor cortex	Seizure	Severe Hemiparesis	No deficit	Glioblastoma	total resection
4	M	52	Sensory cortex	Mild Hemiparesis	no change	No deficit	Adenocarcinoma	total resection
5	M	34	Motor and Sensory cortex	Mderate Hemiparesis	worsen	No deficit	Adenocarcinoma	total resection
6	F	84	Motor and Sensory cortex	Seizure	Mild Hemiparesis	No deficit	Adenocarcinoma	total resection
7	M	32	Motor cortex	Seizure	No deficit	No deficit	Cavernoma	total resection
8	F	32	Premotor cortex	Seizure	Moderate Hemiparesis	No deficit	Astrocytoma	total resection
9	M	70	Sensory cortex	Headache	Sensory deficit	No deficit	Adenocarcinoma	total resection
10	M	62	Premotor cortex	Severe Hemiparesis	no change	No deficit	Abscess	total resection
11	M	70	Premotor cortex	Mild Hemiparesis	worsen	No deficit	Astrocytoma	total resection
12	M	67	Motor and sensory cortex	Mild Hemiparesis	worsen	No deficit	Glioblastoma	subtotal resection
13	F	67	Motor and Sensory cortex	Severe Hemiparesis	no change	No deficit	Adenocarcinoma	total resection
14	M	34	premotor cortex	Headache	Moderate Hemiparesis	No deficit	Astrocytoma	total resection
15	M	54	Premotor cortex	Seizure	No deficit	No deficit	Astrocytoma	subtotal resection

P.O.D.1: Postoperative day 1, P.O.D.14: Postoperative day 14

were seen in 10 patients including: no deficit (n=6), mild hemiparesis (n=3), and moderate hemiparesis (n=1). Their neurologic deficits resolved completely within 14 days (Table). Preoperatively, 7 of 15 patients had mild to severe neurologic deficits and all became symptom free postoperatively (Table). Postoperative CT or MRI scans I revealed a total resection of the tumor in 13 of 15 cases and 2 cases of subtotal resection. Two representative cases are presented:

Case 1

A 62-year-old man was admitted to our hospital with mild weakness of right upper limb. MRI scan revealed single diffusely enhancing tumor under the sensorimotor cortex (Fig. 3A). As he had a past medical history of hepato-cellular carcinoma (HCC), a metastatic brain tumor was suspected. As a full course of radiation therapy failed to produce improvement of the deficits, surgical resection was planned.

With the bipolar-tipped electrode, we intermittently stimulated loci on the cortical surface (4 mA) and noted the motor response to the delivered stimulus. Although the cortex looked completely normal, the location of the tumor was identified using the Stealth Station with an accuracy within 3.0 mm of the computation. The relationship between the location of the tumor and the brain surface structures also coincided with that on the SASS images. Regions in the motor cortex that subserved the face and hand over the tumor were mapped. By separating the central sulcus, the tumor under the motor cortex was exposed. With an ultrasonic aspirator, an attempt to resect the 3 X 4 cm tumor without injuring its overlying cortex was performed. When most of the tumor appeared to be resected, the patient was not able to follow commands using his right upper limb. Tumor resection was stopped at this point. Postoperative MRI scan revealed a total resection of the tumor (Fig. 3B). On histology, the tumor was turned to be adenocarcinoma. Although the weakness of the patient's left upper limb worsened after the surgery, his strength improved substantially within 7 days. The patient received systemic chemotherapy and is alive without local disease at 8 months postoperatively.

Case2

A 17-year-old man was admitted to our hospital with the complain of morning headache and nausea. CT scans revealed diffusely enhancing, partially necrotic appearing tumors in

Figure 3

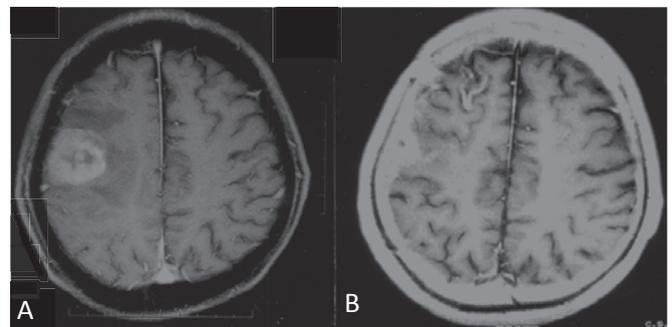
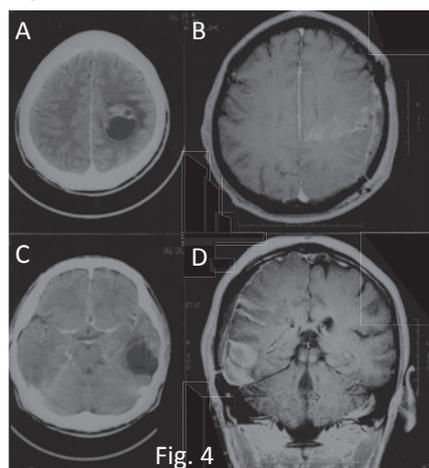


Fig. 3

A: Gadolinium-enhanced T1 weighted MR image of case 1. The tumor occupies the left central sulcus. B: Postoperative MR image shows total resection of the tumor.

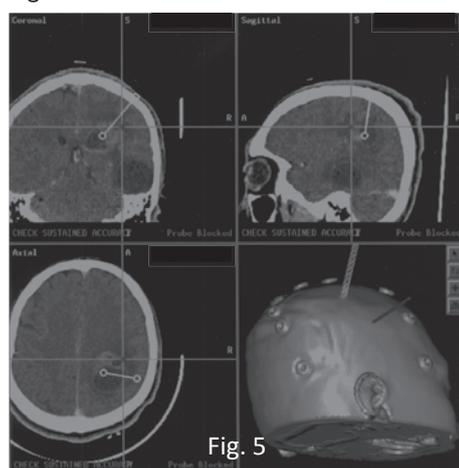
the deep white mater near the right corona radiata and right temporal lobe (Fig. 4A,C). As the patient had a past medical history of cardiac myosarcoma, a brain metastasis was suspected. The neurologic examination was normal. The patient underwent the resection of the tumor in the deep white mater while he was awake. Stimulation mapping of the cortex using 3 mA resulted in individual movements of the face, forearm, and hand. With the use of the Stealth station, an optimal surgical corridor was selected and entry and target points were defined to generate surgical trajectories (Fig. 4B,D). The sensory cortex was resected up to the pial bank of the motor cortex. However, as the resection proceeded, deep cortical stimulation resulted in movements corresponding to the overlying cortical sites within 3 cm of the surface. As the tumor was adherent so as not to injure the motor pathway using both cortical and subcortical stimulation. Postoperative MRI scans revealed total resection of the tumor (Fig. 5). The patient did not have motor weakness after surgery. Sensory examination revealed slightly decreased pinprick, temperature sensation and proprioception in the affected hand. However, the deficits recovered within 12 days. Systemic chemotherapy was given. The patient died from complication from a recurrent primary tumor 4 months later.

Figure 4



A, C: Contrast-enhanced CT scan of case 2. The tumor occupies the deep white matter near the descending motor pathways and temporal lobe in the right hemisphere. B, D: Postoperative gadolinium-enhanced MRI showing total resection of the tumors.

Figure 5



Surgical planning with Stealth Station, showing the surgical trajectory for deep-seated parietal brain tumor in case 2.

Discussion

It is now generally recognized that both survival and quality of life for patients with brain tumors are enhanced by achieving the most extensive surgical resection possible.²⁸⁻³⁰ However, when tumors are located near the motor cortex or submotor pathways, the risk of causing significant motor deficits with aggressive resection is a major concern. It is believed that decreased postoperative morbidity are achieved when using a small skin incision, a centered craniotomy, and an accurate localization of the lesions and related neuronal structures.^{25,26}

We performed the resection of tumors with the combined use of SSAS, a neuronavigation system, and functional stimulation mapping. We used an infrared based system, Stealth Station, for the interactive intraoperative localization of tumors. Ordinarily its reference frame is fixed to the Mayfield clamp to allow correction of relative movements between the patient and the camera array during the operation. This device also allows surgical instruments to perform tracking with an accuracy of 2.2 mm.^{31,32} In this situation, registration

was performed before draping, allowing an adequate skin incision to be marked as well as planning of the bone flap. In our procedure, the patient's head was not fixed with the head holder and the reference frame was fixed to the bed. Fiducial markers were located around the skin incision line to be visualized during surgery so that the correct skin incision for the craniotomy had to be planned before surgery. With the use of SSAS, we could carry out an adequate, small, centered craniotomy in all cases. Registration was performed just before the resection of the tumor for fear that the patient might move his head after registration. Although the patient's head was not fixed with the head holder, localization was made accurately, within 3.5 mm of the computation.

Implicit in the application of neurostimulation techniques for functional cortical mapping is the assumption that the volume of activated tissue is minimal and restricted to the cortical zone directly below the electrode tip. This is true, however, only if the level of stimulation is close to the threshold for local neuronal activation. Supra-threshold stimulation can result in unnecessary current spread around the electrode tip and thereby lead to an incorrect conclusion about the functional role of a particular cortical area. The avoidance of such stimuli also minimizes the degree of neuronal fatigue and cell habituation. Both factors can lead to a degree of response variability that will be confounding.³³ It typically takes less current to evoke motor or sensory responses and interrupt language function when the patient is awake.³⁴ Therefore stimulation functional mapping seems to be preferable in the awake patient.

Yingling et al.²³ pointed out the disadvantages of the use of awake craniotomy. The reasons were multiple. First, the experience of undergoing major surgery while awake is not a pleasant one, and the option of general anesthesia increases comfort and decreases anxiety for the patient. In addition, intrinsic tumors are often grow quite large prior to being detected; with such mass lesions it is important to be able to hyperventilate the patient.

Awareness during surgery may affect the patient adversely, but may also have a benefit with programmed passive learning during anesthesia.³⁵ In 1993, Moerman et al.³⁶ interviewed 26 patients who had experienced awareness with explicit recall of intraoperative events. Most patients felt panic and helplessness related to the inability to move or call for help, and some had frightening sensations of impending death, being left unattended, or sensing that pain might be experienced. Seventy percent suffered significant after effects, including daytime anxiety, sleep disturbances and nightmares, and 3 patients required psychotherapeutic assistance. Ninety percent of the patients who experienced pain during the awareness episode also suffered after effects. Similar findings are observed in other studies³⁶⁻³⁹ and case reports,⁴⁰⁻⁴⁴ which describe patients disabled after such incidents.

Intraoperative events or auditory information presented to patients under general anesthesia may be remembered subsequently.^{44,45} The influence of implicit memory on postoperative behavior is not well studied clinically. Case reports suggest that operating room conversation, especially rude remarks related to the patient, may adversely influence the postoperative course without the patient's conscious knowledge.^{44,46} On the other hand, reduction of the duration of the hospital stay has been reported when patients are presented with positive suggestions predicting a rapid and

comfortable postoperative recovery while under anesthesia.⁴⁷⁻⁵⁰ Taylor et al.⁴⁸ reported that awake craniotomy carried a low morbidity and mortality rates and minimized intensive care unit (ICU) use and total hospital stay in a prospective trial of 200 cases. Intraoperative positive suggestions have a potential for patient benefit in awake craniotomy.

In our series, we explained the merit and safety of keeping the patient awake during surgery and obtained informed consent for our procedure. During surgery, we conversed with patients and encouraged them. All of the patients underwent intraoperative functional brain mapping while awake. Thirteen patients also underwent resection of tumors under local anesthesia, while 2 other patients were sedated with propofol because they hoped to have sedation during the resection of the tumor. Patients with consciousness disorders owing to brain swelling were excluded in this series. In 1 patient (case 4), brain swelling seemed severe on preoperative CT scan (Fig. 3). The swelling was probably caused by radiosurgery performed at another hospital. The patient was alert and underwent resection while awake. During the procedure he required mechanical ventilation but tolerated it well. In our institute, awake craniotomy is chosen for tumor resections in the eloquent area if the patient is alert. All patients were interviewed after surgery; no patients reported discomfort, anxiety, or pain during surgery. Three patients did not recall intraoperative events, including 2 patients who were sedated with propofol during resection of their tumor. Administration of propofol might influence the patient's ability to recall intraoperative events with because of its amnesic effects. No patient experienced after effects.

Yingling et al.²³ resected centrally located tumors using intraoperative stimulation mapping to identify functional motor pathways with multi-channel EMG recording under the general anesthesia. To our knowledge, their article is the first to describe the merit of EMG in detecting stimulation induced motor responses for functional brain mapping. According to their article, in 30% of the cases in their series, EMG monitoring detected motor responses at some point during the operation that otherwise would have gone unnoticed. In 9% of the cases, the EMG recording was the only means of identifying motor responses to stimulation. Even with the use of EMG monitoring, 8 (12%) of 64 patients demonstrated new postoperative deficits.

Successful excision also depends on precise localization, which can be difficult especially for small or deep lesions.^{25,26} With a neuronavigation system, the lesion can be defined and localized relative to the cranium, permitting the use of a smaller craniotomy. Furthermore, it has been proposed that, with easier localization of subcortical and deep lesions, less surgical exploration and retraction will be required, leading to fewer complications, a shorter length of hospital stay, and a shorter operative time.^{25,27}

Taylor et al.⁵¹ described 200 cases of supratentorial intraaxial tumors resected with the use of brain mapping and a frame-based neuronavigation system under local anesthesia. In this series, new postoperative neurologic deficits were only 4.5%. Wagner et al.⁵³ reported the surgery of centrally located tumors using an infrared system and cortical motor stimulation. Postoperative permanent neurologic worsening was found in 1 (5.9%) of 17 patients. Ganslandt et al.³¹ described the resection of tumors around the motor cortex with the use of magnetoencephalography and a neuronavigation system. In

this series, 4% of patients (2 of 50 patients) had deterioration of neurologic function. These data suggest that both anatomic and functional localization decrease new postoperative neurologic deficits during resection of the centrally located tumors.

In our series, fifteen patients underwent awake craniotomy for resection of the centrally located tumor with the combined use of SSAS, stimulation functional brain mapping, and an infrared system. Thirteen of fifteen patients were kept awake during the resection of the tumor. Although postoperative transient worsening of neurologic deficits were seen in 10 patients, their deficit improved completely within 14 days. Seven of fifteen patients had mild to severe neurologic deficits before surgery, however all of them became symptom free after surgery. Intraoperative functional mapping coupled with interactive image-guided surgery provides a reliable method in the resection of these lesions. As functional stimulation mapping cannot always detect neuronal pathways,^{23,31,33,34,51,53} combined use of awake surgery might reduce the postoperative morbidity, because the patient's neurologic condition is known in real time. Our procedure is a viable option for the surgery in the eloquent area.

Conclusion

Awake craniotomy with the combined use of SSAS, stimulation functional brain mapping, and neuronavigation system is an excellent, practical surgical approach to lesions in the eloquent area. Awake craniotomy allows for brain mapping and detection of the patient's neurologic condition in real time. It is well tolerated by patients with various concurrent medical problems and clinical presentations. Our procedure carries low morbidity and mortality rates.

Conflict of interests

The authors indicated no potential conflict of interest.

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