Minimally Invasive Awake Craniotomy using Steiner-Lindquist Stereotactic Laser Guidance

Authors A. Bekar[1], H Bilgin[2], G. Korfalı[2], E. Korfalı[1], H. Kocaeli[1], Ö.Taskapılıoğlu[1]

Affiliations
[1] Department of Neurosurgery, Uludağ University School of Medicine, Görükle, Bursa, Turkey
[2] Department of Anesthesia and Reanimation, Uludağ University School of Medicine, Görükle, Bursa, Turkey

Key words
- stereotactic surgery
- awake craniotomy
- sedation
- cerebral lesions

Abstract

Background: Awake craniotomy permits the continuous assessment of intraoperative neurological functions. In addition, stereotactic laser guidance aids in performing minimally invasive procedures related to the radical resection of lesions located in eloquent and non-eloquent brain regions.
Patients/Material and Methods: Between May 2000 and October 2006, 117 consecutive patients with various intracranial tumoral lesions underwent 141 resection procedures. The eloquent areas were determined with the aid of anatomic landmarks and/or functional MRI (fMRI) examinations. The resection of the lesions was performed under continuous neurological examination. In all cases, postoperative MRI was performed within 24–72 h.
Results: Seventy-seven males and 40 females were included in this study. The mean age of the patients was 52.0 ± 12.6 years. Most of the lesions were located within the parietal lobe. Of the lesions, 33 (23.4%) were located within the cortex, whereas 108 (76.5%) were subcortical. The most common pathologies were metastasis (70 cases) and glioblastome multiforme (27 cases). In 20 (14.2%) of the patients, fMRI was performed preoperatively. Of 21 patients with multiple lesions, 18 underwent 2 craniotomies and 3 underwent 3 craniotomies. The mean operation time was 72 ± 0.3 min, and the mean hospital stay was 3.26 ± 1.82 d. The average lesion size was 11.92 ± 15.26 cm^3. In 7 cases (4.9%), the surgery caused either new neurological deficits or a worsening of the existing deficits; these deficits were permanent in 2 (1.4%) cases. One patient (0.7%) died due to the development of postoperative intracerebral hemorrhage.
Conclusions: Awake craniotomy with the aid of stereotactic laser guidance is a safe procedure that assists in performing minimally invasive resection of lesions in eloquent and non-eloquent brain regions. Although direct intraoperative stimulation was not performed, detection of the functioning areas of the brain with fMRI decreased additional postoperative neurological deficits. Overall, this method decreased the operation time and hospital stay.

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Correspondence
A. Bekar, MD
Department of Neurosurgery
Uludag University
School of Medicine
Görükle
16059 Bursa
Turkey
Tel.: + 90/224/295 2700
Fax: + 90/224/442 9263
abekar@uludag.edu.tr

Introduction

Maximum resection of high-grade gliomas appears to be associated with longer survival, improvement of perioperative symptoms, and better quality of life [1–3]. The surgery of lesions involving the deep and eloquent cortex does, however, carry the risk of neurological deficits that may result from retraction, edema, and/or the resection of eloquent tissue [3]. Therefore, precise preoperative determination of the location of the eloquent brain regions and their relation to the lesion is critical. Awake brain tumor surgery allows intraoperative patient assessment, functional mapping, and safe tumor removal [4–7]. Image-guided neurosurgery, preoperative functional MRI (fMRI), and intraoperative functional mapping methods can facilitate maximal resection of the tumors adjacent to eloquent brain regions [3, 8, 9]. The Steiner-Lindquist stereotactic laser system provides stereotactic localization of intracranial lesions and reduces the size of the craniotomy [10–12]. In this study, we report our experience of performing stereotactic laser-guided awake craniotomy in 117 patients who were treated at our institution for lesions involving eloquent or non-eloquent cortical, subcortical, and deep brain regions.

Patients/Materials and Methods

Between May 2000 and October 2006, 117 patients (141 procedures) underwent surgery that involved awake craniotomy facilitated by Steiner-Lindquist microsurgical stereotactic guidance. The patients comprised 77 men and 40 women with a mean age of 52.0 ± 12.57 (min.: 22; max.: 78) years. The individuals selected for inclusion had clinical and imaging evidence of a supratentorial tumor, not necessarily in an eloquent area, and these underwent elective surgery involving an awake craniotomy. Owing to either an inability or unwillingness to cooperate, only 20 (14.9 %) of the patients with lesions localized at or near the areas of speech and motor functioning underwent a preoperative fMRI examination. We think that the brain mapping can also be indicated in the same patients having lesions of eloquent brain regions.

The objective of the surgeons (A. B, E. K) was to develop awake craniotomy as a routine adjunct for brain tumor removal, rather than reserving it for cases in which the tumor involves only eloquent areas. Awake craniotomy was performed in all cases without brain mapping mainly because it was more advantageous than craniotomy under general anesthesia in certain patients with significant medical comorbidities.

The mass effect and other signs of increased intracranial pressure were not contraindications to the procedure. The antiedema effect of spontaneous hyperventilation (proposed by E. K) was used intraoperatively in such cases. Patients undergoing either first-time or repeat resection were included in this study. Seventeen patients who, for any reason, were unable to cooperate [for example, language difficulty, decreased levels of consciousness, confusion (12 patients), or requirement for a prone position (5 patients)] were excluded from the study.

Surgical technique

All procedures were performed with the aid of a Leksell stereotactic frame (Elekta, Sweden) and computed tomography (CT) guidance. A detailed summary of the stereotactic craniotomy techniques using Steiner-Lindquist stereotactic laser guidance has been reported previously [10].

Awake anesthesia

After the placement of standard anesthesia monitors (electrocardiogram, non-invasive blood pressure, pulse oximetry) and administration of supplemental oxygen at $3\,L \cdot min^{-1}$ via a face mask, end tidal carbon dioxide (E_TCO_2) was monitored via the face mask using a female luer connector attached for sampling during the procedure. Metoclopramide 10 mg was administered *i. v.* to all patients. Patients were sedated using 1 of 3 regimens: propofol infusion ($2\,mg\,kg^{-1} \cdot h^{-1}$) plus bolus fentanyl ($1\,\mu g \cdot kg^{-1}$); propofol infusion ($2\,mg \cdot kg^{-1} \cdot h^{-1}$) plus remifentanil infusion ($0.05\,\mu g \cdot kg^{-1} \cdot h^{-1}$); or dexmedetomidine infusion (initial dose $1\,\mu g \cdot kg^{-1} \cdot 10\,min^{-1}$, then $0.1\,\mu g \cdot kg^{-1} \cdot h^{-1}$) plus bolus fentanyl ($1\,\mu g \cdot kg^{-1}$). The infusion rates were varied to maintain an adequate and constant sedated state (observer's assessment of alertness sedation scale: 3). If the patient spontaneously complained of pain, fentanyl $1\,\mu g \cdot kg^{-1}$ was administered or the remifentanyl infusion rate was increased. Inadequate sedation was treated by increasing the rate of drug infusion.

Assessment of intraoperative neurological function

Resection of the lesions was performed under continuous neurological examination. Spontaneous speech, famous face naming, object picture naming, word comprehension, counting, and motor functions of the extremities were examined continuously.

Table 1 Summary of the clinical data.

	Number of patients	%
gender		
male	77	65.8
female	40	34.1
mean age (range: 22 to 78 years)	52.00 ± 12.57	
lesion localization		
parietal	69	48.9
frontal	38	26.9
temporal	25	17.7
occipital	9	6.3
cortical vs. subcortical		
subcortical	108	76.5
cortical	33	23.4
pathology		
metastasis	70	49.6
glioblastoma multiforme	27	19.1
astrocytoma	13	9.2
meningioma	11	7.8
oligodendroglioma	9	6.3
cavernoma	2	1.4
others	9	6.3
mean craniotomy size	10.8 ± 6.68 cm^2	
second craniotomy	18	12.8
third craniotomy	3	2.12
mean hospitalization period	3.26 ± 1.82 d	
mean lesion size (min.: 0.25 cm^3; max.: 80 cm^3)	11.92 ± 15.26	

Results

Patient demographics

Lesions were localized most frequently in the parietal lobe (48.9 %). The clinical characteristics of the patients are presented in **Table 1**. Sixteen patients who had multiple lesions underwent more than one craniotomy. The mean operation time was 80.41 ± 27.21 min and the mean duration of hospitalization was 3.26 ± 1.82 d (min.: 1 d; max.: 11 d). The mean lesion volume was 11.92 ± 15.26 cm^3 (min.: 0.25 cm^3; max.: 80 cm^3). Pathological evaluation revealed metastasis and glial tumor in 70 (49.6 %) and 39 (34.6 %) patients, respectively. Postoperative transient (new neurological deficits or worsening of existing deficits) and permanent neurological deficits were observed in 5 (3.5 %) and 2 (1.4 %) patients, respectively. One (0.7 %) patient died due to an intracerebral hematoma that developed postoperatively. **Table 2** and **3** summarize the relevant clinical data (symptoms, pathology, and lesion location.

Discussion

Awake craniotomy has been described as an approach for the removal of all supratentorial tumors regardless of the involvement of eloquent cortex [9]. Resection of intrinsic brain tumors located in close proximity to eloquent cortex carries a high risk of postoperative deficits. Intraoperative MRI, frame-based or image-guided stereotactic tumor resection techniques, smaller cranial and dural openings, minimal exposure of the normal

Table 2 The patients' presenting symptoms.

	n	%
neurological deficit		
motor weakness	47	31.5
speech disorder	7	4.6
seizure	38	25.5
headache	24	16.1
dizziness	6	4.02
none	12	8.05
others	15	10.0

Table 3 Surgical outcome and complications.

Neurological outcome	Number of patients	%
unchanged	94	66.7
improved	16	11.3
no pre- or postoperative neurological deficit	63	44.7
new postoperative deficits or worsening of the existing neurological deficits	7	4.9
transient	5	3.5
permanent	2	1.4
perioperative epilepsy	4	2.8
perioperative agitation	2	1.4
exitus	1	0.7

brain, and intraoperative stimulation techniques can all be used to tailor the extent of resection and reduce this risk [7, 10, 13–15].

Awake craniotomy is a safe and inexpensive technique that allows safe removal of lesions adjacent to eloquent brain areas whilst preserving neurological functions. Moreover, a single, small incision is generally sufficient for lesion resection [4, 6, 7, 9]. However, iatrogenic postoperative deficits still may be encountered. These sensory and motor deficits are mostly realized during the operation whereas some high cortical neurological dysfunctions may not be revealed during surgery [16]. This technique has been reported to be associated with low complication rates and with a considerable reduction in resource use by virtue of minimizing both intensive care and total hospital stay without compromising patient care [9].

Anesthesia performed during awake craniotomy does, however, have some special requirements. Adequate analgesia, sedation, hemodynamic stability, and a safe airway should be maintained in awake patients [5]. After evaluation of different anesthetic techniques for awake craniotomy, the combination of propofol and remifentanyl was deemed to be preferable. Although most patients were initially fearful of the prospect of awake craniotomy, the majority tolerated the procedure well [7, 17]. In our study, we performed awake craniotomy under sedation and analgesia with stereotactic guidance. No significant anesthetic complications were observed in our patients and none required conversion to general anesthesia. An advantage of awake craniotomy is that it enables the employment of spontaneous hyperventilation, which is used for the treatment of perioperative brain edema and allows safe resection; thus, none of our patients required mannitol or other antiedema agents. Two patients experienced agitation as a consequence of pain due to inappropriate positioning, and these individuals were treated with higher doses of midazolame.

The precise determination of the functioning areas of the brain is important for successful tumor resection. This can be carried out intraoperatively by direct cortical and subcortical stimulation or preoperatively by indirect methods [7, 14, 18]. One method used to measure functional competence during awake craniotomy is CT-guided stereotactic cortical stimulation accompanied by repetitive neurological and language assessments. fMRI and laser-guided procedures are additional methods that may be employed [19–21]. Localization of functional areas with direct electrical cortical stimulation during Steiner-Lindquist stereotactic laser-guided awake craniotomy allows optimal tumor resection without the risk of additional neurological deficits [22]. fMRI may also be a substitute for intraoperative mapping in epilepsy surgery [19, 20]. Although fMR activation has been reported to be correlated with intraoperative cortical mapping [21], accurate cortical localization, particularly of higher functions such as writing or calculating, is still a major problem with fMRI [23]. However, there are fMRI studies reporting a high percentage of false positive/negative results (9%) associated with higher functions such as writing, language, and calculation [16]. Consequently, critical surgical decisions should not be based exclusively on this modality [24]. We performed fMRI on 20 patients, and an assessment of the fMRI results and lesions revealed that none of the patients developed additional permanent neurological deficits. Kral et al., concluded that awake craniotomy, requiring only one surgical procedure, was advantageous when compared to two-step functional mapping of the dominant hemisphere with microelectrodes [25]. In our study, anatomic localization and continuous neurological assessments during surgery enabled the removal of small lesions with acceptable complication rates.

The Steiner-Lindquist microsurgical stereotactic approach targets small deep or subcortical lesions, thereby enabling the exact localization of the lesion; consequently, a small craniotomy incision is generally sufficient for resection. This minimally invasive approach not only decreases postoperative complication rates but also reduces the period of hospitalization [10]. In our study, the mean duration of hospitalization was 3.4 ± 2.1 d. Intraoperative neurological deficits were detected in 7 (4.9%) cases, which were transient in 5 and consisted of motor deficits without causing morbidity related to the operation. Three patients (2.1%) experienced seizures during the operation. These patients were on anticonvulsant therapy, and since there was no increase in seizure frequency during the follow-up they did not require an increase in drug dosage. As reported previously, our median operation time of 72 ± 0.38 min supports the premise that this procedure is also time efficient [7].

Stereotactic craniotomy is a minimally invasive procedure that allows more than one procedure to be performed during the same time interval [10]. The use of stereotactic localization of the target allows this minimally invasive procedure to be carried out with a small skin incision and a minicraniotomy [12]. Due to the presence of multiple lesions, 21 patients (14.9%) underwent multiple craniotomies (2 craniotomies for 18 patients, and 3 craniotomies for 3 patients). These patients were without deficits but had cortical and subcortical lesions at or near eloquent brain regions.

In summary, awake craniotomy with the aid of Steiner-Lindquist stereotactic laser-guidance is a safe procedure that assists in performing minimally invasive resection of lesions located in eloquent brain regions. Although direct intraoperative stimulation was not performed in this study, detection of the functioning areas of the brain with fMRI decreased the development of postoperative neurological deficits. Therefore, this method decreases the operation time, hospital stay, and postoperative development of neurological deficits.

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