Intraoperative Multi-Information-Guided Resection of Dominant-Sided Insular Gliomas in a 3-T Intraoperative Magnetic Resonance Imaging Integrated Neurosurgical Suite

Dong-Xiao Zhuang, Jin-Song Wu, Cheng-Jun Yao, Tian-Ming Qiu, Jun-Feng Lu, Feng-Ping Zhu, Geng Xu, Wei Zhu, Liang-Fu Zhou

OBJECTIVE: **To evaluate the clinical application of 3-T intraoperative magnetic resonance imaging (iMRI), awake craniotomy, multimodal functional mapping, and intraoperative neurophysiologic monitoring (IONM) for resection of dominant-sided insular gliomas.**

METHODS: **From March 2011 to June 2013, 30 gliomas involving the dominant insular lobe were resected in the IMRIS 3.0-T iMRI integrated neurosurgical suite. For 20 patients, awake craniotomy with cortical electrical stimulation mapping was performed to locate the language areas. For 10 patients who were not suitable for awake surgery, general anesthesia and functional navigation were performed. Diffusion tensor imaging tractography-based navigation, continuous motor evoked potential monitoring, and subcortical electrical stimulation mapping were applied to localize and monitor the motor pathway in all cases. iMRI was used to assess the extent of resection. The results of intraoperative imaging, IONM, and the surgical consequences were analyzed.**

RESULTS: **Intraoperative imaging revealed residual tumor in 26 cases and led to further resection in 9 cases. As a result, the median extent of resection was increased from 90% to 93% ($P = 0.008$) in all cases, and from 88% to 92% ($P = 0.018$) in low-grade gliomas. The use of iMRI also resulted in an increase in the percentage of gross and near total resection from 53% to 77% ($P = 0.016$). The rates of permanent language and motor deficits resulting from tumor removal were 11% and 7.1%, respectively.**

CONCLUSIONS: **The combination of iMRI, awake craniotomy, multimodal brain mapping, and IONM tailored for each patient permits the maximal safe resection of dominant-sided insular glioma.**

INTRODUCTION

The insular cortex, first described by Johann Christian Reil in 1809,[1] is a portion of the cerebral cortex folded deep within the lateral sulcus between the temporal lobe and the frontal lobe. It is believed to be involved in a large variety of functions such as gustatory, olfactory, auditory, and vestibular senses; pain perception; visceral sensorimotor processing; motor control; volitional swallowing; speech planning; sympathetic control of cardiovascular tone; and cognitive and emotional

Key words
- Electric stimulation
- Glioma
- Insula
- Intraoperative magnetic resonance imaging
- Neuronavigation

Abbreviations and Acronyms
BOLD: Blood-oxygen-level-dependent
DTI: Diffusion tensor imaging
EOR: Extent of resection
ESM: Electrical stimulation mapping
FA: Fractional anisotropy
FLAIR: Fluid-attenuated inversion recovery
FOV: Field of view
HGG: High-grade glioma
iMRI: Intraoperative magnetic resonance imaging
IONM: Intraoperative neurophysiologic monitoring
LLA: Lateral lenticulostriate artery
MEP: Motor evoked potential
MRI: Magnetic resonance imaging
TE: Echo time
TI: Inversion time
TR: Repetition time

Department of Neurologic Surgery, Huashan Hospital, Shanghai Medical School, Fudan University, Shanghai Neurosurgical Center, Shanghai, P.R. China

To whom correspondence should be addressed: Jin-Song Wu, M.D., Ph.D.
[E-mail: wjsongc@126.com]

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functions.[2,3] As a functionally complex structure, the insula also harbours peculiar anatomic features and specific neuronal connectivity with surrounding cerebral structures. It is superficially adjacent to perisylvian language areas (dominant side), the primary auditory area, and both the primary motor and sensory areas of the lower face in addition to their subcortical pathways.[4] Deep to the central part of the insula lie the extreme capsule, claustrum, external capsule, putamen, and globus pallidus.[5] Moreover, the insula is closely related to the middle cerebral artery, and its main blood supply is from short and medium-sized perforators of the M2 segment.[3,6] Therefore, tumors involving this area pose a significant challenge to neurosurgeons.

We retrospectively studied 30 patients with insular gliomas on the dominant side treated with awake craniotomy, multimodal functional brain mapping, intraoperative neurophysiologic monitoring (IONM), and 3-T intraoperative magnetic resonance imaging (iMRI)-based navigation.

METHODS

Patient Population

From March 2011 to April 2013, 30 consecutive patients (19 men and 11 women, ranging in age from 27 to 67 years, mean 45 $\pm$ 11 years) with gliomas involving the left insular lobe were resected in the 3-T iMRI integrated neurosurgical suite (IMRIS, Winnipeg, Canada), which was set up in Huashan Hospital in August 2010. Among them, 29 patients underwent a primary craniotomy, except 1 who had a recurrent insular tumor 6 years after the first resection of a left temporal low-grade glioma (LGG). All cases were evaluated with preoperative magnetic resonance imaging (MRI) (contrast T1-weighted and T2-weighted fluid-attenuated inversion recovery [FLAIR] imaging). For all tumors, the Berger-Sanai Insular Glioma Classification System,[7] in which the insula is divided into 4 zones, was used to assign the tumor location. Histopathologic review was performed based on the 2007 World Health Organization (WHO) classification of tumors of the central nervous system.[8] This study was approved by the Huashan institutional review board, Fudan University. Written informed consent was obtained from all patients.

Surgical Procedures

For surgical navigation, both structural and functional MRI were performed before the operation using our iMRI system. The layout of the iMRI system was described in our previous report.[9] The clinical use of iMRI was approved by the state food and drug administration in December 2010. For nonenhancing lesions, T2-weighted FLAIR imaging (spin-echo sequence; repetition time [TR], 7600 milliseconds; echo time [TE], 96 milliseconds; inversion time [TI], 900 milliseconds; fractional anisotropy [FA], 9°; slices, 60; slice thickness, 2 mm; matrix size, 256 $\times$ 180; field of view [FOV], 240 $\times$ 240 mm^2; voxel size, 1.3 $\times$ 0.9 $\times$ 2 mm^3; axial section) was performed, and for enhancing tumors, T1 contrast imaging (three-dimensional magnetization-prepared rapid gradient echo sequence; TR, 1900 milliseconds; TE, 2.93 milliseconds; TI, 900 milliseconds; FA, 9°; FOV, 250 $\times$ 250 mm^2; matrix size, 256 $\times$ 256; voxel size, 1.0 $\times$ 1.0 $\times$ 1.0 mm^3) was performed after intravenous contrast administration of gadolinium diethylenetriamine penta-acetic acid to acquire the structural image. In all cases, diffusion tensor imaging (DTI) was acquired with a single-shot spin-echo echo-planar imaging sequence (TR, 7600 milliseconds; TE, 90 milliseconds; slice thickness, 3 mm; slice space, 0 mm; matrix size, 128 $\times$ 128; FOV, 230 $\times$ 230 mm^2; voxel size, 1.8 $\times$ 1.8 $\times$ 3 mm^3) of 40 slices covering the entire cerebrum except the cerebellum. The blood-oxygen-level-dependent (BOLD) functional MRI was also performed in all patients. The motor and language pathways as well as the activation of the motor and language areas were reconstructed and merged into three-dimensional structural images using a postprocessing workstation (Syngo MultiModality Workplace [Siemens AG, Munich, Germany]).[10]

In this study, the anesthetic regimen (awake or general anesthesia) was selected based on the preoperative evaluation of hemispheric dominance and the tolerance of the patient. Awake anesthesia was preferred for dominant-sided tumors except for patients with contraindications (i.e., patients unable or unwilling to cooperate with awake craniotomy; evidence of severe intracranial hypertension). All awake craniotomies were performed under the monitored anesthesia care protocol. The detailed awake anesthesia procedures were described in our previous report.[11] Patients were positioned supine with the ipsilateral shoulder elevated on a rest pad. The head was turned 30–45° contralaterally. Then, a tailored frontotemporal craniotomy was performed from a pterional approach, with the bone window being adjusted according to the extension of the tumor. After opening the dura, the somatosensory evoked potential was recorded with a 6 $\times$ 1 contact subdural strip electrode. The central sulcus was identified by an N20 to P20 phase reversal. Then, the strip electrode was placed on the primary motor cortex to monitor the afterdischarge activity from language mapping and the motor evoked potential (MEP) during tumor resection. Direct cortical stimulation for language mapping was then performed with 3 patient tasks (counting, picture naming, and word reading). Our language mapping procedure has been described elsewhere.[11] For patients under general anesthesia, preoperative BOLD image-based functional navigation was used for language mapping.

After the motor and language areas were identified and marked with sterile tags (**Figure 1A**), resection of the tumor was performed with careful protection of those eloquent areas. Opening of the sylvian fissure or resection of the frontal or temporal operculum was performed according to the size, location, and opercular involvement of the tumor. Then, subpial resection of the tumor was conducted with guidance from structural (T2 FLAIR or T1 contrast image) and functional (BOLD, DTI tractography) navigation. For all 30 cases, DTI tractography-based navigation combined with continuous transcortical MEP monitoring and subcortical electrical stimulation mapping (ESM) were performed to localize the pyramidal tracts and monitor the motor pathway. Resection of the tumor was continued until 1 of the 3 circumstances emerged: 1) the patient presented with a deterioration of language or motor function; 2) continuous MEP monitoring showed an amplitude decline greater than 50% (excluding declines resulting from technical issues) or impairment beyond spontaneous variation with inconstant MEP recordings (**Figure 1B**); 3) the margin of the tumor was reached on the navigation. Then, the surgical manipulation was stopped, and iMRI was performed to assess the extent of resection (EOR). If intraoperative imaging demonstrated residual tumor, the surgeon reinspected the resection cavity and