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Clinical Study

Awake language mapping and 3-Tesla intraoperative MRI-guided volumetric resection for gliomas in language areas

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ABSTRACT

The use of both awake surgery and intraoperative MRI (iMRI) has been reported to optimize the maximal safe resection of gliomas. However, there has been little research into combining these two demanding procedures. We report our unique experience with, and methodology of, awake surgery in a movable iMRI system, and we quantitatively evaluate the contribution of the combination on the extent of resection (EOR) and functional outcome of patients with gliomas involving language areas. From March 2011 to November 2011, 30 consecutive patients who underwent awake surgery with iMRI guidance were prospectively investigated. The EOR was assessed by volumetric analysis. Language assessment was conducted before surgery and 1 week, 1 month, 3 months and 6 months after surgery using the Aphasia Battery of Chinese. Awake language mapping integrated with 3.0 Tesla iMRI was safely performed for all patients. An additional resection was conducted in 11 of 30 patients (36.7%) after iMRI. The median EOR significantly increased from 92.5% (range, 75.1–97.0%) to 100% (range, 92.6–100%) as a result of iMRI ($p < 0.01$). Gross total resection was achieved in 18 patients (60.0%), and in seven of those patients (23.3%), the gross total resection could be attributed to iMRI. A total of 12 patients (40.0%) suffered from transient language deficits; however, only one (3.3%) patient developed a permanent deficit. This study demonstrates the potential utility of combining awake craniotomy with iMRI; it is safe and reliable to perform awake surgery using a movable iMRI.

1. Introduction

Gliomas are the most common primary brain tumors and are associated with a poor prognosis.[1–3] The standard treatment for gliomas is tumor resection followed by adjuvant radiotherapy and chemotherapy. An increasing body of literature[4–7] demonstrates that the extent of resection (EOR) is a predictor of survival, despite a lack of class I evidence.[8–10] However, the aggressive resection of gliomas located in eloquent areas carries the risk of neurologic deficits that can lead to a loss of quality of life, which may subsequently affect survival.[11] Thus, for neurosurgeons, the main challenge in glioma surgery is achieving the maximal tumor resection while still preserving eloquent areas. Various advanced techniques and methods, including neuronavigation, intraoperative MRI (iMRI), 5-aminolevulinic acid and electrocortical mapping, have facilitated the maximal safe resection of gliomas in eloquent areas.[12–17] Image guidance using neuronavigation, which is based on preoperative imaging, has been used extensively for several decades to aid in the resection of intracranial tumors. However, intraoperative brain shift poses a limitation for conventional neuronavigation. Therefore, iMRI has attracted increasing interest in the past decade because it effectively detects tumor remnants and compensates for intraoperative brain deformation.[18] However, with the application of iMRI alone, it is difficult to preserve neurologic function reliably and to delineate a real-time safe boundary for tumor resection, particularly in gliomas involving language areas. Currently, awake language mapping is generally accepted as the gold standard for language localization and has been used with success in several languages of the Indo-European family.[14,19–21] However, the feasibility and reliability of this technique as applied to the Chinese population (that is, Sino-Tibetan family speakers), have seldom been evaluated quantitatively.[22] In addition, although both iMRI and awake language mapping are independent and established techniques, few studies[23–27] have reported their combination. Experience in combining these two complicated modalities is limited, and the evidence is not sufficiently robust to draw a conclusion regarding the effectiveness of this combination.

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In this prospective study, we describe our approach and experience with the integration of awake language mapping and movable 3.0 Tesla (T) iMRI for the resection of gliomas in language areas. We aimed to both increase the EOR and to decrease the postoperative morbidity by combining these techniques.

2. Patients and methods

2.1. Patients

Patients with tumors located in language areas as indicated by preoperative MRI were considered for tumor resection aided by the combination of iMRI and awake language mapping. Patients were selected using the following inclusion criteria: (i) the patients were adults of Han ethnicity; (ii) they usually spoke Chinese in daily life; (iii) they were right-hand dominant; and (iv) cerebral gliomas were preoperatively suspected. The exclusion criteria included the following: (i) patients with contraindications to MRI scanning, intraoperative neurophysiologic monitoring, or awake craniotomy (including patients with pacemakers, obstructive sleep apnea or severe intracranial hypertension); and (ii) patients whose pathologic diagnoses were not gliomas. All of the patients underwent language functional assessment using the Aphasia Battery of Chinese,[28] which is the Chinese standardized adaptation of the Western Aphasia Battery. The Aphasia Quotient (AQ) score (spontaneous speech, comprehension, repetition and naming) was used to measure language ability. The preoperative cognitive state was also assessed using the Mini Mental State Examination.[24] Patients with severe language deficits (AQ < 50) or cognitive disorders (Mini Mental State Examination score < 23) were excluded.[24] Written informed consent was obtained from all patients. This study was undertaken at the Huashan Hospital (Shanghai, China) with approval from the Huashan Institutional Review Board.

2.2. Preoperative examination and evaluation

Cognitive status and language function were preoperatively assessed by a neuropsychologist as previously mentioned. The patients were diagnosed with language deficits if they scored below 93.8 on the AQ preoperatively.[29] Preoperative consultations by neurosurgeons and anesthesiologists occurred on the day before the operation. Patients were trained by neurosurgeons to perform the tasks of counting, naming objects and reading single words. Anesthesiologists were in charge of the interpretation for intraoperative discomfort and cooperation.

Preoperative brain images were obtained in the diagnostic room of an iMRI-integrated neurosurgical suite (IMRIS, Winnipeg, Manitoba, Canada) using a movable 3.0 T scanner (MAGNETOM Verio 3.0 T, Siemens AG, Erlangen, Germany) 1 day prior to surgical intervention. The imaging protocol included a contrast-enhanced three-dimensional (3D) magnetization-prepared rapid-gradient echo (MPRAGE) sequence (time of repetition (TR), 1900 milliseconds; time of echo (TE), 2.93 milliseconds; flip angle, 9 degrees; field of view (FOV), 250×250 mm^2; matrix size, 256×215; slice thickness, 1 mm; acquisition averages, 1) or a fluid-attenuated inversion recovery (FLAIR) sequence (TR, 9000 milliseconds; TE, 96 milliseconds; TI, 2500 milliseconds; flip angle, 150 degrees; slice thickness, 2 mm; FOV, 240×240 mm^2; matrix size, 256×160); diffusion tensor imaging (TR, 7600 milliseconds; TE, 91 milliseconds; slice thickness, 3 mm; slice space, 0 mm; FOV, 230×230 mm^2; matrix size, 128×128; voxel size, $1.8 \times 1.8 \times 3$ mm^3; 20 directions); and blood oxygen level-dependent functional MRI (TR, 3000 milliseconds; TE, 30 milliseconds; FOV, 240×240 mm^2; matrix size, 96×96; slice thickness, 3 mm) for the preoperative localization of language areas. The arcuate fasciculus and activations of the language areas were then reconstructed into 3D objects and superimposed onto the structural data (Fig. 1A–C) using a post-processing workstation (Syngo MultiModality Workplace, Siemens AG). The 3D relationships between the lesion and the language areas were provided to the neurosurgeons for decision making. On the day of surgery, the reconstructed series were imported into the surgical navigation system.

2.3. Awake craniotomy

A monitored anesthesia care (MAC) approach was adopted for all patients. After the anesthesiologists administered premedication by infusing 0.02–0.03 mg/kg midazolam and 5 mg tropisetron, they prepared the patient with intravenous lines, a central venous catheter, an arterial line, and a urethral catheter. The supraorbital, supratrochlear, zygomaticotemporal, auriculotemporal, greater occipital, and lesser occipital nerves of both sides were then blocked using a mixture of lidocaine (0.67%) and ropivacaine (0.5%). Once the patient was brought into moderate sedation with boluses of intravenous propofol, the head was fixed into its fitted position using a custom-designed high-field MRI-safe head holder (DORO Radiolucent Headrest System, Pro Med Instruments GmbH, Freiburg, Germany), which was integrated with an IMRIS operating room table and head coils (IMRIS). Once the scalp was prepared and draped, remifentanil (0.01–0.03 μg/Kg/min) or dexmedetomidine (0.1–0.7 μg/Kg/h) was administered for analgesia. To minimize brain swelling, mannitol (1 g/kg) was intravenously infused before the dura was opened. A low dose of remifentanil (0.01 μg/Kg/min) or dexmedetomidine (0.1 μg/Kg/h) was administered during mapping. Because of the minimal draping, as described below, no laryngeal mask airway or endotracheal tubing was applied during the iMRI acquisition phase in these patients. Throughout the operation, supplemental inspired oxygen was delivered by nasal cannula or facemask.

2.4. Intraoperative language mapping

A constant-current generator (Epoch XP, Axon Systems Inc., Hauppauge, New York, USA) was used for intraoperative electrophysiologic monitoring during the procedure. MRI-safe subdermal needle electrodes (Chinese patent No. ZL201110074011.0) were inserted into the scalp and the target muscles to record compound muscle action potentials before craniotomy. For intraoperative direct cortical stimulation (DCS), a monophasic square-wave pulse was delivered at 60 Hz through a 5 mm wide bipolar electrode. The stimulation current ranged from 2 mA to 6 mA. While DCS was in progress, a 4- or 6-contact-strip subdural electrode was used to record after-discharge activity. The presence of after-discharge potentials indicated that the stimulation current was too high and the threshold would be decreased by 0.5–1 mA. This threshold was adopted as the upper limit of the sequential stimulation current. Using this ideal stimulation current, the patient completed three language tasks: counting from one to 50, picture naming, and word reading. Language deficits were classified as speech arrest, anomia, or alexia.[19] Speech arrest was distinguished from dysarthria, which is caused by an involuntary muscle (mouth or pharyngeal muscle) contraction. Each cortical site was checked three times (Supplementary Fig. 1). If necessary, DCS and direct subcortical electrical stimulation were used for motor mapping. All of the positive sites were marked on the surface of the cortex with sterile tags, and the locations of these tags were recorded with photographs and navigational snapshots. Any adverse effects during the operation caused by electrical stimulation were recorded.