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Neoplasm

Functional magnetic resonance imaging–guided resection of low-grade gliomas

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Abstract

Background: We sought to determine the safety and efficacy of using functional magnetic resonance imaging (fMRI) to guide the resection of low-grade gliomas (LGG).

Methods: From September 1997 to February 2003, fMRI was performed in 16 patients (age, 15-43 years) before an attempted surgical resection of LGG. Functional imaging was used to identify and coregister eloquent cortices pertinent to motor (10), speech (3), motor and speech (2), and short-term memory and speech (1) activation with respect to the tumor using a 1.5-T interventional MRI system. Intraoperatively acquired T_2-weighted and turbo-fluid attenuated inversion recovery images were used to assess the completeness of surgical resection.

Results: Tumors included 10 oligodendrogliomas, 4 astrocytomas, 1 dysembryoplastic neuroepithelial tumor, and 1 pleomorphic xanthoastrocytoma. In every case, the preoperative brain activation study accurately determined the location of neurologic function. After surgery, one patient had a transient hemiparesis and another had a temporary apraxia. Ten patients had radiographically complete resections and 5 with oligodendrogliomas had incomplete resections because of the proximity of their tumors to functional areas. Only one patient with an astrocytoma in the motor strip received postoperative radiation therapy. To date, radiographic tumor progression has not been seen in any patient with either a partial or a complete resection with a median follow-up of 25 months (range, 12-87 months).

Conclusions: Functional MRI was accurate for identifying areas of neurologic function before surgical resection of LGG. Patients with complete radiographic resections or with incompletely resected oligodendrogliomas can be safely followed radiographically after surgery. Radiation therapy was reserved for infiltrating astrocytomas that were not completely resectable.

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1. Introduction

The optimal treatment of low-grade gliomas (LGG) remains controversial. In many instances, patients with an intracerebral lesion that has the magnetic resonance imaging (MRI) characteristics suggestive of a LGG are often followed with repeat sequential MRI particularly if the lesion is located near eloquent cortex. In other patients, surgery in the form of a biopsy, partial resection, or gross total resection is attempted with the approach determined by the location of the tumor [10]. Patients with tumors that abut or involve eloquent cortex often undergo stereotactic biopsy. Such patients either are followed by sequential MRI or are treated with adjuvant radiation therapy (RT) or chemotherapy (CTX) if indicated by the histopathologic findings [10,22]. Some progressive oligodendrogliomas with 1p/19q deletions have been treated with adjuvant CTX alone [22].

Once the diagnosis is confirmed, patients who have a partial resection are often treated with immediate postoperative RT or CTX or are followed radiographically until tumor progression is detected. Once progression is confirmed, these patients are either treated with immediate RT

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or CTX or undergo repeat surgical resection if possible, followed by observation and repeat imaging or RT or CTX. The administration of adjuvant therapy without a histopathologic diagnosis is an uncommon practice [15]. The reasons for administering early RT or CTX after diagnosis based on tumor typing and grading are being defined [9].

Recent advances in neurosurgery have included image guidance neuronavigational systems and intraoperative MRI (ioMRI) [3,4,7,12,13,16,18-20]. Neuronavigational systems rely on the computer manipulation of computed tomography or MRI data that is obtained either several days before or immediately before the planned surgical procedure. A principal disadvantage of these systems is the potential for shift of the brain (and hence, the tumor that is to be resected) once the dura mater is opened and cerebrospinal fluid is removed. In contrast, ioMRI allows for near real-time imaging to provide visual updates with respect to the extent of surgical resection. Such ioMRI will reflect changes in tumor position (due to brain shift) and will enable the surgeon to alter the operative approach. Additional functional capabilities that can assist the neurosurgeon to plan the surgical approach include functional MRI (fMRI) [7]. By determining the location of eloquent cortices relative to motor, speech, and/or memory using fMRI either the day before surgery or immediately before the induction of general anesthesia, we have resected LGG in locations where surgery was felt to carry a prohibitive risk for neurologic morbidity. We evaluate the results in 16 patients where fMRI guidance was used to aid the resection of their LGG and examine the clinical efficacy and the operative morbidity of this surgical approach.

2. Materials and methods

2.1. Magnetic resonance imaging system

The MRI system is a short-bore 1.5-T scanner (Gyroscan ACS-NT, Philips Medical Systems, Best, Netherlands) with strong imaging gradients (23 mT/m, 105 mT/m per millisecond) that allow for the generation of echo planar imaging (EPI) pulse sequences that are commonly used for fMRI experiments. The total length of the MRI system is 180 cm with an inner bore diameter of 60 cm that can extend to 100 cm beyond the flared openings. The magnet is actively shielded and produces a 5-G footprint that measures 7.8 $\times$ 5.0 m in dimensions. A head coil composed of 2 circular loops arranged as a phased array allows excellent operative access to the patient with high imaging quality.

The imaging capabilities of this MRI system are those of conventional high-field scanners. The EPI-capable gradients permit diffusion-weighted imaging and brain activation studies such as fMRI to be performed. Real-time, interactive MRI allows images to be manipulated with respect to geometry and contrast parameters immediately after acquisition. Such images are displayed on the MRI console and on liquid crystal display (LCD) screens located in the MRI suite adjacent to the scanner. The LCD screens can be moved freely in the MRI suite via ceiling-mounted rails that allow the images to be viewed at either end of the MR scanner.

2.2. Magnetic resonance imaging suite

A pedestal table on which surgical procedures can be performed was positioned on-axis within the MRI system (Fig. 1). The table top can move freely along the resulting track and can be locked on the surgical pedestal, at the center of the magnet, and at a position extending 40 cm beyond the distal end of the magnet. A carbon fiber Malcolm-Rand head frame (Elekta, Decatur, GA) attaches to the table top that permits exact reproduction of the scan planes during prolonged operative procedures where intraoperative imaging is repeated on several occasions. This repositioning capability allows the neurosurgeon to visualize the operative site for areas of concern that may represent residual tumor that were not visible because of brain shift after partial tumor resection. Surgery can be performed on the pedestal either at the near end of the room outside the 5-G line with standard non–MRI-compatible surgical instrumentation (Fig. 2) or on the opposite side of the magnet using MRI-compatible instruments. The MRI suite meets the specifications for a conventional operating room, yet is used for standard diagnostic MRI between surgical cases. On the evening before the operative procedure, the MRI suite is terminally cleaned and subsequently treated as a sterile surgical environment. Because of potential safety risks, color-coded pocketless scrub suits are worn to identify interventional MRI personnel and to prevent the inadvertent introduction of potentially dangerous ferromagnetic objects into the suite.

2.3. Patients

From January 1997 to February 2003, 16 patients (10 males, 6 females) were considered for fMRI-guided resection of their brain tumors that were confirmed to be LGG on permanent pathological examination (Table 1). The mean age of the patients was 31 years and the median age was 36 years (range, 10-43 years). Tumor locations included the right frontal (n = 5), right parietal (n = 1), left frontal (n = 6), left temporal (n = 3), and left parietal (n = 1) lobes of the brain.

Fifteen patients (94%) presented with seizures. One patient (6%) was asymptomatic. All patients (100%) had normal findings from neurologic examinations before surgery. Of 16 patients, 12 (75%) were having their first surgical procedure. Two patients had their oligodendrogliomas previously resected 2 and 7 years earlier. One patient had an MRI-guided biopsy of an astrocytoma in the posterior right frontal lobe before an attempted fMRI-guided surgical resection. Another patient had the medial posterior left temporal dysembryoplastic neuroepithelial tumor removed and examined at another institution before being referred for an image-guided surgical resection.

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