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Technique

Correlation of factors predicting intraoperative brain shift with successful resection of malignant brain tumors using image-guided techniques

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Abstract

Background: Intraoperative brain shift may cause inaccuracy of stereotactic image guidance on the basis of preoperatively acquired imaging data. The purpose of our study was to determine whether factors predicting brain shift affect the success of image-guided resection of malignant brain tumors.

Methods: We retrospectively studied 54 patients who underwent image-guided resections of histopathologically confirmed malignant brain tumors (9 metastases, 45 high-grade gliomas). Precautions were taken during surgery to minimize brain shift, but intraoperative imaging was not performed. The following factors predictive of intraoperative brain shift were assessed: tumor size, periventricular location, patient age, prior surgery or radiation therapy, patient positioning, use of mannitol, and length of operative time. Postoperative magnetic resonance imaging was obtained in all cases within 48 hours of surgery to assess extent of resection.

Results: Perioperative mortality was 0% in our series; perioperative morbidity was 3 of 54 patients (5.5%); 1 patient required reoperation for a hematoma, and 2 had transient neurological deficits. Successful resection was accomplished in 93% of tumors less than 30 cm^3 compared with 63.6% of tumors greater than 30 cm^3 (P = .026, Fisher exact test). This difference was more pronounced for patients with malignant gliomas. However, other factors predictive of intraoperative brain shift were not associated with unsuccessful resection.

Conclusions: Intraoperative brain shift does not significantly affect the likelihood of successful resection of malignant brain tumors smaller than 30 cm^3. Larger tumors are less likely to be successfully resected, although factors other than brain shift can contribute to unsuccessful resection.
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Keywords: Image-guided neurosurgery; Malignant gliomas; Metastases; Stereotaxy; Brain shift

1. Introduction

Malignant brain tumors, including brain metastases and high-grade gliomas, are the most common brain tumors and are significant causes of morbidity and mortality [34]. Malignant brain tumors are usually treated with multiple modalities including surgery, stereotactic radiosurgery, external beam radiation, and chemotherapy [5]. The benefits of surgery for single brain metastases are well documented [30]; the benefits of aggressive resection of high-grade gliomas are debated, but recent literature tends to support aggressive surgical intervention [1,2,16,20].

Image-guided, stereotactic volumetric techniques aid in the resection of malignant brain tumors. These techniques permit minimally invasive craniotomies, facilitate identification of tumor intraoperatively, and help surgeons avoid critical brain structures [9-12,28]. These advantages are particularly important for surgery on malignant brain tumors, including high-grade gliomas, which tend to arise near critical regions of brain and are often difficult to distinguish from normal tissue. However, there are limitations to image-guided, stereotactic volumetric techniques; the most significant may be intraoperative brain shift. Brain shift may occur as a result of patient positioning, dural opening, the use of mannitol, tumor resection, and cerebrospinal fluid (CSF) drainage by entry into cisterns or the ventricular system. Several published studies demonstrated

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and quantified intraoperative brain shift using optical techniques [15,31,32] and intraoperative magnetic resonance imaging (MRI) [21,23,25]. In these studies, the brain surface shifted up to 2.4 cm during surgery; the amount and direction of shift, and the significance of various factors in causing brain shift, varied in different studies.

Brain shift has the potential to make image-guided surgery on the basis of preoperatively acquired images inaccurate; however, it is not clear whether this inaccuracy results in worse outcomes after resection of malignant brain tumors. The purpose of this retrospective study was to test the hypothesis that factors predicting intraoperative brain shift would be correlated with unsuccessful resection of malignant brain tumors. We found that tumor size, but none of the other factors that predict brain shift, correlated with the success of tumor resection using image-guided, stereotactic volumetric techniques.

2. Methods

2.1. Patient population

This is a retrospective chart review of all patients who fulfilled the following criteria: (1) image-guided craniotomy for resection of tumor, (2) histopathologically confirmed malignant brain tumor (glioblastoma multiforme, anaplastic astrocytoma, anaplastic oligodendroglioma, or brain metastasis), and (3) postoperative MRI with and without gadolinium (Gd) enhancement within 48 hours of surgery. For the period of September, 1997, to February, 2003, 54 patients fulfilled these criteria: 45 patients with malignant gliomas, and 9 patients with brain metastases. This study was conducted under Mount Sinai School of Medicine Institutional Review Board guidelines.

2.2. Surgical techniques

All patients underwent placement of adhesive fiducial skin markers on the scalp on the morning of surgery, followed by Gd-enhanced MRI using a conventional frameless stereotactic protocol (2-mm-thick axial T1-weighted sections with 0-mm interval). Patients were then brought to the operating room and anesthesia induced. All patients were treated with dexamethasone, antibiotics, and anticonvulsants.

The Treon image-guided system (Medtronic SNT, Louisville, Co) was used in all cases for image guidance. Intraoperative navigation was used in all cases to determine the extent of tumor resection. When tumor was located near eloquent cortex, intraoperative electrophysiological monitoring was performed. When patients underwent reoperation for tumor after radiation therapy, frozen tissue sections were sent intraoperatively to distinguish tumor from radiation necrosis. Several techniques were used to minimize intraoperative brain shift; these techniques are listed in Table 1. No patients had intraoperative imaging or intraoperative updating of preoperatively obtained fiducial points.

Table 1
Techniques for minimizing brain shift during resection of malignant brain tumors

Hyperventilation until tumor debulking begins
Avoid mannitol and other diuretics
Avoid CSF diversion
Delineate tumor margins in 3 dimensions before debulking
Avoid penetration of tumoral cyst

2.3. Magnetic resonance imaging evaluation

We estimated tumor size using the modified ellipsoid method previously described and validated for intracerebral hematomas [8,19]. Residual enhancing tumor on postoperative MRI was defined as nodular enhancement on Gd-enhanced T1-weighted images obtained within 48 hours of surgery (Fig. 1); nodular enhancement, but not smooth linear enhancement (Fig. 2), around the tumor bed on early postoperative imaging predicts tumor regrowth in prospective studies [1,3]. Tumors were defined as periventricular when any part of the tumor touched the ventricular wall.

Successful tumor resection was defined by complete absence of nodular enhancement surrounding the tumor bed on postoperative MRI, or less than 5% of nodular enhancement deliberately left in situ by the surgeon because of information obtained intraoperatively (see "Results" section).

2.4. Statistical analysis

A statistician in the Biomathematics Department, Mt Sinai School of Medicine, New York, NY (LR), using commercially available software, conducted statistical analysis. Eleven of the 54 patients in our study underwent multiple surgeries at Mt Sinai Hospital. For these 11 patients, only outcomes from the first surgeries performed at Mt Sinai Hospital were included in our analysis, in accordance with commonly accepted statistical practice. We first analyzed all patients with malignant tumors, then analyzed the subset of patients with malignant gliomas separately. We chose to analyze patients with malignant gliomas separately because of their different surgical characteristics; specifically, malignant gliomas are more infiltrative than metastases, and are often more difficult to distinguish morphologically from normal tissue. To adjust for multiple comparisons, a significance level of $P = .025$ rather than $P = .05$ was used. We chose to analyze tumor size in bins (smaller than or greater than or equal to 30 cm^3) in part because of a bimodal distribution in our patient population, and in part to maximize the usefulness of our results in practice. In view of the generally high incidence of successful tumor resection, we used Fisher exact test rather than χ^2 test to compare qualitative independent variables. We used contingency table analyses to compare continuous variables. The independent sample t test was used to compare the ages of patients with and without successful resections. Because of a nonparametric distribution of operative times, we used the Wilcoxon W

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