Neurosurgical Focus

Neurosurg Focus 4 (4): Article 8, 1998

Surgical treatment of low-grade gliomas in the intraoperative magnetic resonance imager

---

Claudia Martin, M.D., Eben Alexander III, M.D., Terry Wong, M.D., Ph.D., Richard Schwartz, M.D., Ph.D., Ferenc Jolesz, M.D., and Peter McL. Black, M.D., Ph.D.

Sections of Neurosurgery and Neuroradiology, Brigham and Women's Hospital, Harvard University School of Medicine, Boston, Massachusetts

---

Radical resection of low-grade gliomas can decrease the incidence of recurrence, the time to tumor progression, and the incidence of malignant transformation. The authors present a series of 25 patients who underwent craniotomy and resection of low-grade tumor in an intraoperative magnetic resonance (MR) imager. This is an open configuration 0.5-tesla imager developed by The Brigham and Women's Hospital and General Electric, in which a patient can be placed to undergo surgery. Gross-total removal was accomplished under real-time image guidance. These intraoperative images allow definitive localization and targeting of the lesions and accommodate anatomical changes that may occur during surgery. The authors consistently found that the extent of abnormality seen on the intraoperatively obtained films of resection was larger than that apparent in the surgical field of view alone. Intraoperative imaging made accurate surgical identification of these abnormal areas and subsequent resection possible. Patients with tumors adjacent to or within motor or language cortex underwent resection while awake, with monitoring of neurological function. In these cases, an aggressive resection without increased neurological morbidity was accomplished using the image guidance in conjunction with serial testing. A 1-month postoperative MR image was obtained in all patients. These correlated with the final intraoperative images obtained after the resection was completed. Only one patient had a mild postoperative deficit that remained at the 1-month follow-up examination. As the long-term outcome in patients with low-grade gliomas has been shown to correspond to the degree of resection, surgical resection in which intraoperative MR imaging guidance is used can be an invaluable modality in the treatment of these tumors.

Key Words * low-grade glioma * intraoperative magnetic resonance imaging * neuronavigation

---

Throughout this century, advances in the treatment of many neurological diseases have been tied to technological advances. This is clearly evident in the area of stereotactic neurosurgery in which the evolution of stereotactic devices and the development of computerized tomography and magnetic resonance (MR) imaging provided the neurosurgeon with increasing precision and accuracy. During the last decade, navigational devices that couple the imaging capabilities of computerized tomography and MR with stereotactic techniques have provided an unprecedented degree of surgical guidance. The recent development of an intraoperative MR imager is the next step on this continuum and has made the concept of real-time intraoperative guidance a reality. The capability of integrating information from images obtained intraoperatively with a navigational guidance system and correlating this with the surgeon's field of view provides unequivocal accuracy of localization and guidance of resection. This may potentially increase the safety and effectiveness of the surgical treatment of low-grade gliomas.

THE GENERAL ELECTRIC INTRAOPERATIVE MR IMAGER

The intraoperative MR imager was developed through a collaborative effort between the Brigham and Women's Hospital (BWH) and General Electric beginning in 1990 that resulted in a prototype being installed at the BWH in 1994.[5] Physical access to the patient in standard MR imagers is prevented by the closed configuration of the magnet and the radiofrequency and gradient coils. The essential innovation in the design of this 0.5-tesla magnet was the separation of the superconducting coils, resulting in an open configuration imager with a central 54-cm wide vertical gap (Fig. 1). A surgeon can stand on either side of the patient placed inside the imager and images can be obtained throughout the procedure without the need for any movement of the patient table. The images can be simultaneously viewed by the surgeon on monitors suspended within the patient access gap and by the radiologist at consoles placed directly outside of the operating room.

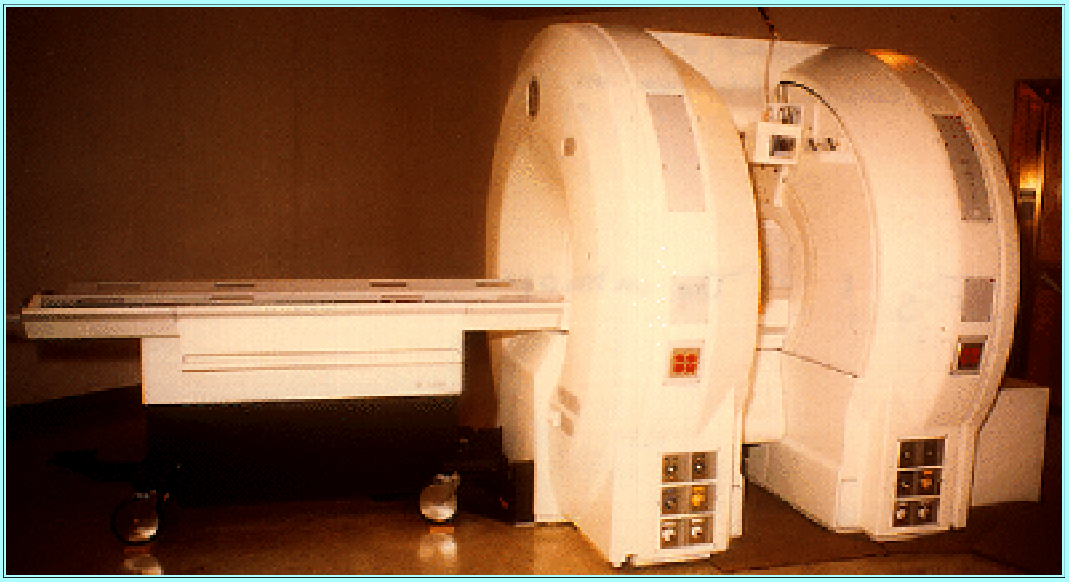

Fig. 1. Photograph showing the intraoperative MR imager.

All standard neurosurgical procedures can be performed within this imager. Patients can be positioned supine or prone on the MR table, and the table can be advanced through the bore of the magnet or through the separated partitions of the magnet. The patient can also be placed inside the imager in a removable chair that can be adjusted to accommodate any sitting position. In addition to the standard surgical drapes, drapes are affixed to the inner aspects of the open configuration to assure a sterile field. The surgeon wears a sterile vest over the gown to allow turning within this space without compromising sterility.

Surgical instruments and tools need to be customized to be MR compatible: they cannot be ferrous or any other material that may cause an artifact in the field during imaging. At the present time the full array of MR-compatible surgical instruments required for a craniotomy is available, as well as an MR-compatible headholder (Mayfield; Ohio Medical Instrument Co., Inc., Cincinnati, OH), microscope (Studor Medical

Engineering Ag, Rhenfall, Switzerland), and craniotome (Midas Rex, Fort Worth, TX).

A flexible transmit/receive radiofrequency coil is applied to the perimeter of the planned surgical area and is incorporated into the sterile drapes. The image volume is 30 cm in diameter and images can be obtained in any plane. All standard image sequences are possible and contrast can be administered during surgery to evaluate the enhancement of lesions. Although a 0.5-tesla imager cannot provide the image resolution that is possible with the standard 1.5-tesla diagnostic imagers, the anatomical detail provided is more than sufficient for intraoperative guidance. Obtaining a series of images in one plane requires between 60 and 120 seconds, depending on the sequence being used.

A navigational system (Flashpoint 5000; IGT, Boulder, CO) was built into this imager to provide real-time imaging for surgical guidance. When using this mode, single slice images can be updated within 2 to 12 seconds.

CLINICAL MATERIAL AND METHODS

Twenty-five patients, nine women and 16 men between the ages of 21 to 54 years, underwent craniotomy for tumor resection in the intraoperative MR imager. Preoperative MR imaging findings were consistent with a probable diagnosis of low-grade glioma in all patients. Those patients with lesions in or near areas of eloquent cortex, such as the motor strip or language areas, underwent the surgery while awake and under local anesthesia and sedation. The remainder received a general anesthetic. The pathological results included six astrocytomas, 12 oliogodendrogliomas, and seven mixed gliomas (Table 1).

TABLE 1 CHARACTERISTICS OF 25 PATIENTS UNDERGOING INTRAOPERATIVE MR IMAGING FOR TUMOR RESECTION			
Tumor Type/ No. of Cases	Sex, Age (yrs)	Tumor Location	Percent Resection*
astrocytoma			
1	M, 29	rt frontal	100
2	M, 40	rt parietal	80
3	M, 31	lt temporal	100
4	M, 37	lt occipital	100
5	M, 41	rt parietal	70
6	M, 34	rt occipital	100
oligodendroglioma			
1	M, 54	lt frontal	100
2	M, 68	lt frontal	100
3	M, 54	rt frontal	90
4	F, 38	rt frontal	100
5	F, 38	rt frontal	100
6	F, 40	lt frontal	100
7	F, 27	rt temporal	100
8	M, 32	rt frontotemporal	90
9	F, 32	lt frontal	100
10	M, 21	lt frontal	100
11	M, 38	rt frontal	100
12	F, 50	rt frontal	90
mixed glioma			
1	M, 38	lt parietal	100
2	F, 45	rt frontal	100
3	F, 33	lt frontal	90
4	M, 35	rt frontal	100
5	M, 21	lt temporal	100
6	F, 38	lt frontal	100
7	M, 27	lt frontal	80

* Percentage based on MR abnormality.

Both T_1- and T_2-weighted multiplanar image sequences were used to guide the resections. Images were obtained prior to skin incision, craniotomy, and/or dural opening with a finger or a MR marker placed on each to plan the optimal opening. Images were again acquired to plan the corticectomy, target deep lying lesions, and evaluate the relationship of the lesion to pertinent anatomical structures during the resection. The resection of tumor was guided by serial images until resection was considered complete by the surgeon viewing both the surgical field and the images acquired. A contrast agent was administered intravenously to patients in whom any areas of enhancement had been demonstrated on preoperative imaging. Any tumor lying within eloquent cortex or deep nuclei/white matter tracts was not resected. In the awake patients, tumor resection was discontinued if there was evidence of any change in neurological function. If the T_2-weighted abnormalities extended beyond the T_1-weighted area of abnormality, T_2-weighted images were used to define the boundary of resection. Areas of tissue that were abnormal on MR images but were difficult to localize in the bed of resection by visual inspection alone were localized by using an MR-visible pointer during imaging, with repositioning and reimaging as necessary. Tissue that did not look grossly abnormal to the surgeon but had an abnormal image characteristic was resected if this could be accomplished safely. The percentage of resection achieved at the end of surgery was assessed by both the surgeon and radiologist.

All patients were evaluated for any new postoperative neurological deficits. Magnetic resonance images were obtained 1 month after surgery and were compared with the final intraoperative MR images.

RESULTS

The craniotomies were performed in the intraoperative MR unit without any technical difficulties. A complete resection of the tumor mass with the aid of image guidance was achieved in 18 patients. A subtotal resection was achieved in seven patients, with a 90% resection in four and a 70 to 80% resection in three. Intraoperative images in these patients revealed residual tissue abnormalities involving or encroaching on deep structures or motor/language cortex. Five of these patients began to show some change in neurological function at which time resection was discontinued.

Postoperatively, one patient in whom a 90% resection of a right frontotemporal glioma was accomplished had a new left-sided paresis. This had improved by the 1-month follow-up evaluation but had not entirely resolved. Four patients had mild transient deficits that had resolved at the time of the 1-month follow-up examination. All of these patients had undergone resections involving the supplementary motor cortex.

DISCUSSION

The treatment of low-grade gliomas remains an area of controversy and debate. Treatment options have included observation alone, biopsy sampling for confirmation of diagnosis followed by observation, and surgical resection at the time of diagnosis, at the time of increased growth, or when symptoms worsen. Radiation has been both recommended and discouraged and chemotherapy is recommended for some classes of gliomas. Variations in the biological activity of low-grade gliomas have contributed to making treatment decisions difficult.[7,16,18,21,22,24,25]

The imaging capabilities of MR and computerized tomography have allowed earlier diagnosis of these tumors. This in turn provides the possibility for a treatment intervention well before a potential dedifferentiation into a more malignant grade or an increase in tumor size causing secondary neurological compromise occurs. Recent studies have shown that surgical resection of low-grade gliomas can result in an improved survival time for patients and that the degree of resection correlates with a better outcome.[4,23]

It is clear that the benefit from early surgery must be evaluated against the risk of causing a significant neurological deficit. Deep-seated lesions or those that are close to or involve eloquent cortex are often considered too perilous to resect aggressively. Conversely, subtotal resections can occur because the gross appearance of the lesion may not seem to be abnormal to the surgeon throughout the entire extent of the mass.

The intraoperative MR imager provides a method by which these issues can be addressed. Other navigational systems such as frameless stereotactic systems and three-dimensional reconstructions[2,3,6,8,10-12,14,17,19,23,26,28] can provide a degree of increased accuracy and safety. However, surgical inaccuracies can occur in framed stereotactic systems secondary to distortions of the frame, errors in setting coordinates, and artifacts of imaging caused by the presence of a head frame or dental hardware. In the frameless systems, errors in the registration process and image distortion can make stereotactic calculations invalid.[9,15,20,27] However, the major limitation of these systems is that the navigation is based on preoperative images alone. Anatomical changes can occur intraoperatively secondary to cerebrospinal fluid egress, administration of osmotic agents, reactive edema, or the resection of the tumor mass, which can result in brain shift or sag.[9] This can make navigation increasingly inaccurate as a resection proceeds.

The major advantage of intraoperative MR imaging is that it provides updated real-time information whenever the surgeon wishes to have it. Magnetic resonance imaging is the modality of choice for gliomas; both T_1- and T_2-weighted images and contrast administration for enhancing tumors provide optimal operative image guidance. The skin incision as well as the skull and dural opening can be planned and executed under image guidance at the onset of the procedure, allowing the size of the craniotomy to be minimized. Pertinent anatomical structures such as the motor strip can be identified on the images and definitively correlated with the anatomy presenting in the surgical field. The optimal surgical approach can be chosen and executed under image guidance, allowing tumors to be accessed with minimal injury to normal tissue. Real-time imaging with the LED guidance system can be used to aid the approach to deep lesions. For subcortical lesions, serial images in which a pointer or digit is used, can guide the corticectomy (Fig. 2).

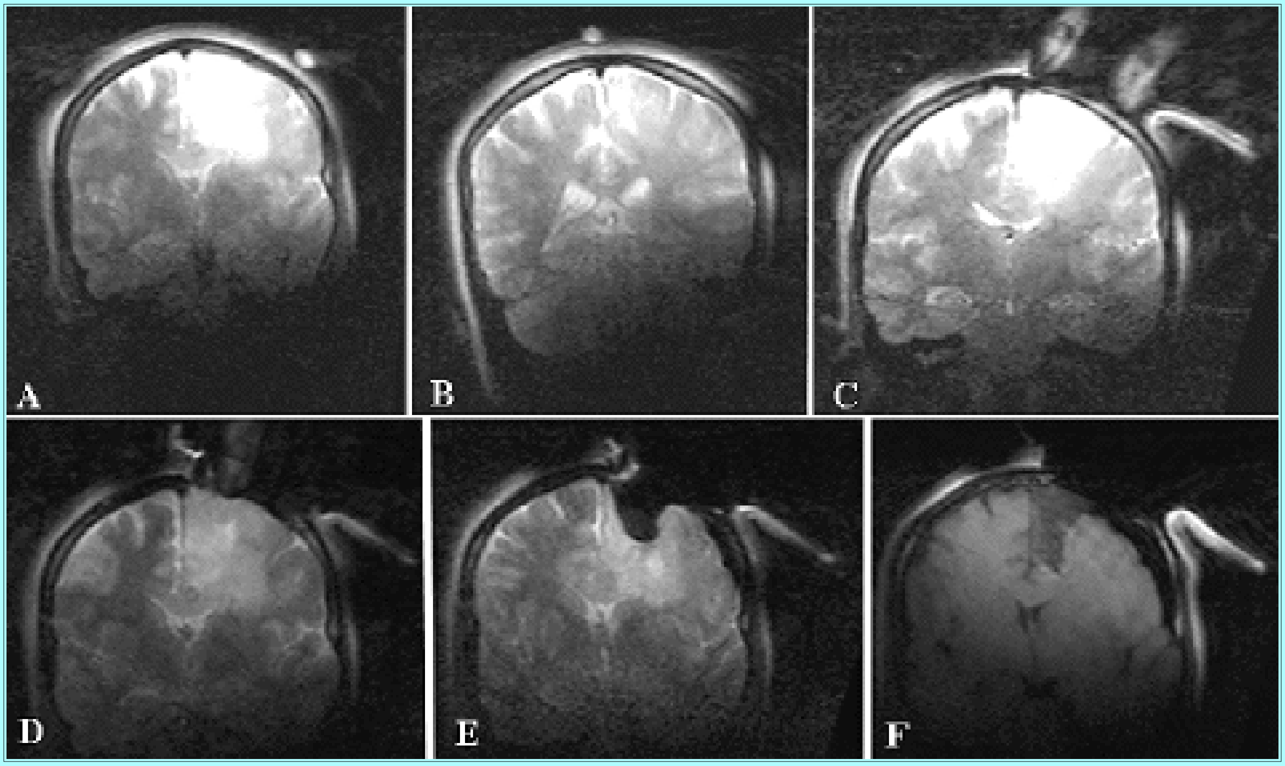

Fig. 2. Intraoperative coronal MR images obtained in a patient with a parasagittal frontal mass. A: A T_2-weighted image of a bead placed on the skin to establish the lateral edge of the planned craniotomy. B: A T_2-weighted image of the posterior aspect of the tumor and a bead over the midline (several slices posterior to A in the same series). C: A T_2-weighted image of finger localization prior to dural opening. D: A T_2-weighted image showing localization of optimal corticectomy. E: A T_2-weighted image obtained to evaluate the lateral margin during resection. F: A T_1-weighted image obtained after dural closure to evaluate any hemorrhage in the surgical bed.

The ability to identify and correlate definitively the surgical anatomy with the radiographic anatomy on the serial images allowed the resections in these patients to be aggressive while still remaining safe (Figs. 3 and 4).

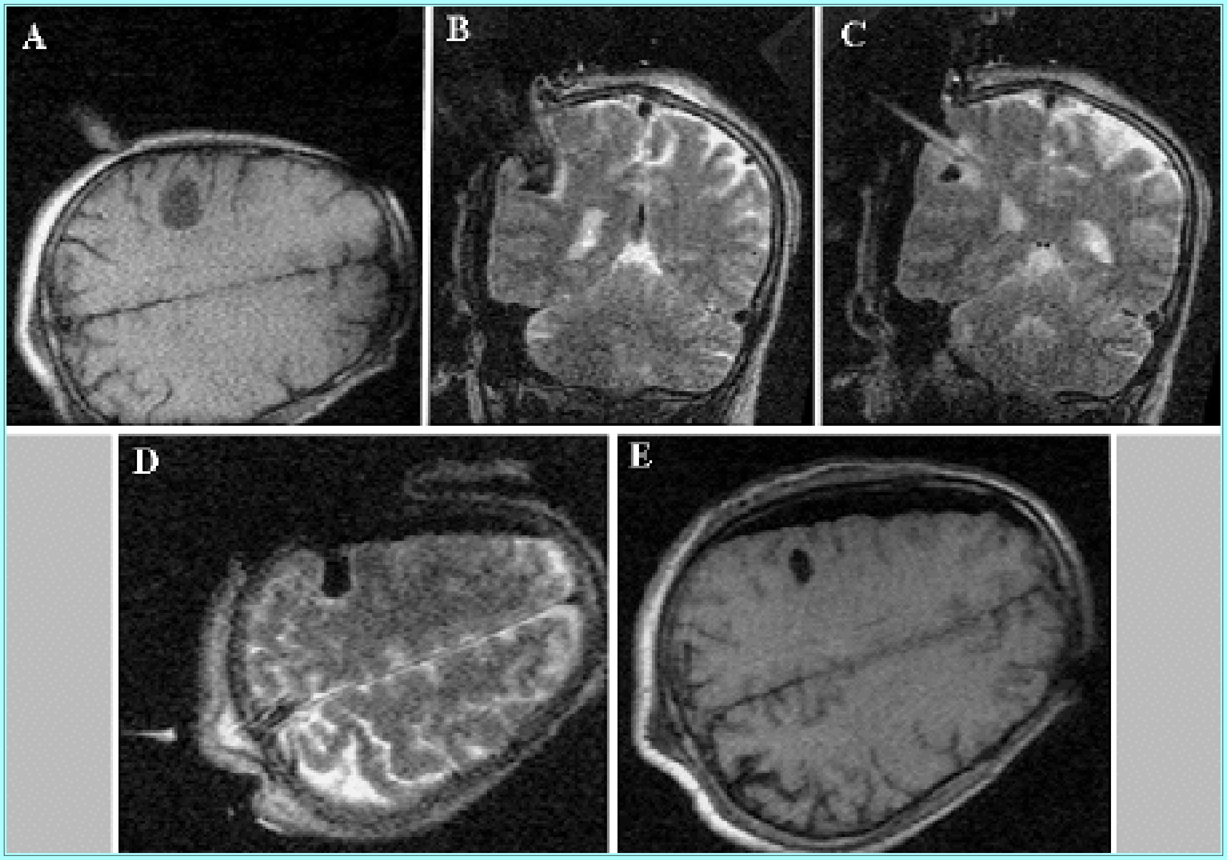

Fig. 3. Magnetic resonance images showing the resection of an astrocytoma directly posterior to motor strip. A: Initial axial T_1-weighted intraoperative image demonstrating a hypodense mass and finger for localization on the skin. B: A T_2-weighted coronal image revealing a finger placed in the resection bed to localize remaining radiographically abnormal tissue. C: A T_2-weighted image obtained to localize tissue still requiring resection with a syringe pointer. D: Axial T_2-weighted image obtained to evaluate the completeness of resection prior to closing the dura. E: Final axial T_1-weighted image postclosure showing a fluid-filled resection cavity. Note the degree of sag of the brain tissue.

This was particularly important in the patients with tumors adjacent to the motor strip or areas of language cortex. Additionally, it was helpful to be able to establish the exact position of major arteries, identified as flow voids on MR imaging, prior to encountering them within the surgical field. The margins of gross abnormality identified with the aid of magnification did not always correlate with the margins of image abnormalities in the majority of the cases. In these cases the resections would have been subtotal without the intraoperative image guidance.

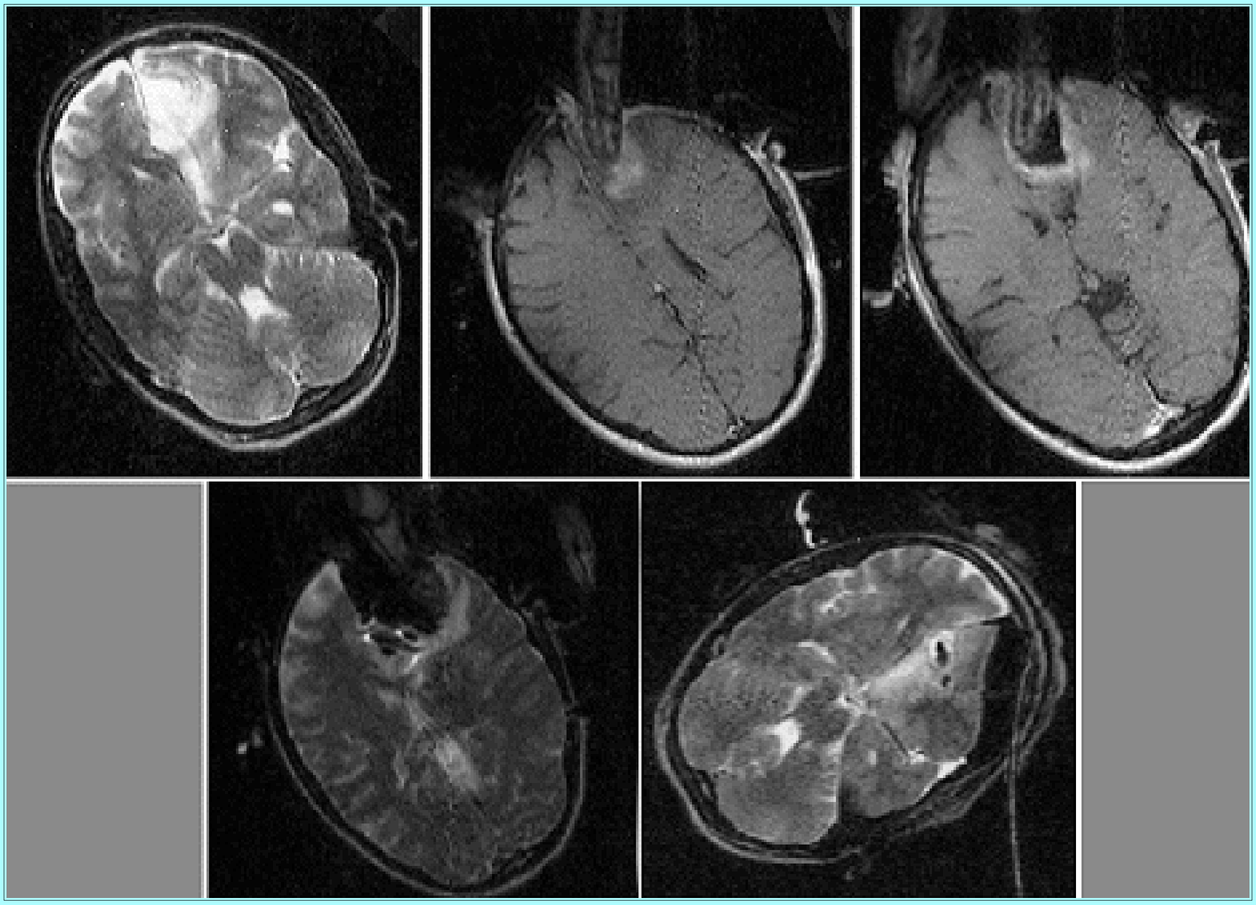

Fig. 4. Magnetic resonance images showing resection of a left frontal oligoastrocytoma. A: Initial axial T_2-weighted intraoperative image showing the lesion. B and C: Axial T_1-weighted images showing finger localization to guide resection of abnormal tissue. D: A T_2-weighted image obtained to localize the lateral abnormal tissue. E: A T_1-weighted image obtained after closure. Note the shift in the brain tissue.

The importance of delineating tumor margins cannot be minimized because the extent of resection of gliomas may have a direct effect on survival rates in patients with low-grade gliomas. Small low-grade gliomas (volume lt 10 cm^3) show a significant decrease in the incidence of recurrence, the time to tumor progression, and a decreased incidence of malignant transformation if radically resected. When larger, the percentage of resection affects the time to recurrence.[1,4,13,22] The margins of a low-grade astrocytoma are usually well defined on T_2-weighted images but are often indistinguishable from surrounding brain on visual inspection. There is a decreased incidence of high-grade recurrences in patients in whom a 100% resection was achieved.

We recognize that accurate anatomical identification intraoperatively does not wholly protect against a postoperative deficit. Although our results have been good using local anesthetic and sedation, with only one patient developing a new deficit, electrophysiological correlation with the operative and image anatomy would be optimal. Electrocorticographic technology in the intraoperative MR imager, not presently available, is being developed and should soon be ready for implementation. It is also unclear whether T_1-weighted abnormalities or the usually more extensive T_2-weighted abnormalities should be used intraoperatively to guide the resection of low-grade gliomas for optimal long-term patient outcome. Correlation of the pathological findings in tissue specimens with the intraoperative images will help to provide an answer.

The intraoperative MR imager provides a method by which the neurosurgeon can achieve an optimal resection with maximal safety. The ability to accomplish this is unprecedented and we believe that this will have a direct impact on the immediate and long-term outcome of patients with low-grade gliomas.

References

1. Albert FK, Forsting M, Sartor K, et al: Early postoperative magnetic resonance imaging after resection of malignant glioma: objective evaluation of residual tumor and its influence on regrowth and prognosis. **Neurosurgery 34:**45-61, 1994

2. Barnett GH, Kormos DW, Steiner CP, et al: Intraoperative localization using an armless, frameless stereotactic wand. Technical note. **J Neurosurg 78:**510-514, 1993

3. Barnett GH, Kormos DW, Steiner CP, et al: Use of a frameless, armless stereotactic wand for brain tumor localization with two-dimensional and three-dimensional neuroimaging. **Neurosurgery 33:**674-678, 1993

4. Berger MS, Deliganis AV, Dobbins J, et al: The effect of extent of resection on recurrence in patients with low grade cerebral hemisphere gliomas. **Cancer 74:**1784-1791, 1994

5. Black PM, Moriarty T, Alexander EA III, et al: Development and implementation of intraoperative magnetic resonance imaging and its neurosurgical applications. **Neurosurgery 41:**831-845, 1997

6. Bucholz RD, Smith KR, Henderson J: Intraoperative localization using a three dimensional optical digitizer.**Proc SPIE 1894:**312-322, 1993

7. Cohadon F, Aouad N, Rougier A, et al: Histologic and non-histologic factors correlated with survival time in supratentorial astrocytic tumors. **J Neurooncol 3:**105-111, 1985

8. Galloway RL, Maciunas RJ: Stereotactic neurosurgery. **Crit Rev Biomed Eng 18:**181-205, 1990

9. Galloway RL Jr, Maciunas RJ, Latimer JW: The accuracies of four stereotactic frame systems: an independent assessment. **Biomed Instrument Technol 25:**457-460, 1991

10. Golfinos JG, Fitzpatrick BC, Smith LR, et al: Clinical use of a frameless stereotactic arm: results of 325 cases. **J Neurosurg 83:**197-205, 1995

11. Guthrie BL, Adler JR Jr: Computer-assisted preoperative planning, interactive surgery, and frameless stereotaxy. **Clin Neurosurg 38:**112-131, 1995

12. Henderson JM, Smith KR, Bucholz RD: An accurate and ergonomic method of registration for image guided neurosurgery. **Comput Med Imaging Graph 18:**273-277, 1994

13. Janny P, Cure H, Mohr M, et al: Low grade supratentorial Astrocytomas. Management and prognostic factors. **Cancer 73:**1937-1945, 1994

14. Kelly PJ: Volumetric stereotactic surgical resection of intra-axial brain mass lesions. **Mayo Clin Proc 63:**1186-1198, 1988

15. Kondziolka D, Dempsey PK, Lunsford LD, et al: A comparison between magnetic resonance

imaging and computed tomography for stereotactic coordinate determination. **Neurosurgery 30:**402-407, 1992

16. Laws ER Jr, Taylor WF, Clifton MB, et al: Neurosurgical management of low-grade astrocytoma of the cerebral hemispheres. **J Neurosurg 61:**665-673, 1984

17. Lunsford LD, Parrish R, Albright L: Intraoperative imaging with a therapeutic computed tomographic scanner. **Neurosurgery 15:**559-561, 1984

18. Lunsford LD, Somaza S, Kondziolka D, et al: Survival after stereotactic biopsy and irradiation of cerebral nonanaplastic, nonpilocytic astrocytoma. **J Neurosurg 82:**523-529, 1995

19. Maciunas RJ, Berger MS, Copeland B, et al: A technique for interactive image guided neurosurgical intervention in primary brain tumors. **Neurosurg Clin North Am 7:**245-266, 1996

20. Nauta HJW: Error assessment during "image guided" and "imaging interactive" stereotactic surgery. **Comput Med Imaging Graph 18:**279-287, 1994

21. Philippon JH, Clemenceau SH, Fauchon FH, et al: Supratentorial low grade astrocytomas in adults. **Neurosurgery 32:**554-559, 1993

22. Piepmeier J, Christopher S, Spencer D, et al: Variations in the natural history and survival of patients with supratentorial low-grade astrocytomas. **Neurosurgery 38:**872-879, 1996

23. Roberts DW, Strohbehn JW, Hatch JF, et al: A frameless stereotaxic integration of computerized tomographic imaging and the operating microscope. **J Neurosurg 65:**545-549, 1986

24. Soffietti R, Chio A, Giordana MT, et al: Prognostic factors in well-differentiated cerebral astrocytomas in the adult. **Neurosurgery 24:**686-692, 1989

25. Shaw EG, Daumas-Duport C, Scheithauer BW, et al: Radiation therapy in the management of low-grade supratentorial astrocytomas. **J Neurosurg 70:**853-861, 1989

26. Tan KK, Grzeszczuk R, Levin DN, et al: A frameless stereotactic approach to neurosurgical planning based on retrospective patient-image registration. Technical note. **J Neurosurg 79:**296-303, 1993

27. Walton L, Hampshire A, Forster DMC, et al: A phantom study to assess the accuracy of stereotactic localization, using T_1-weighted magnetic resonance imaging with the Leksell stereotactic system. **Neurosurgery 38:**170-178, 1996

28. Watanabe E, Mayanagi Y, Kosugi Y, et al: Open surgery assisted by the neuronavigator, a stereotactic, articulated, sensitive arm. **Neurosurgery 28:**792-800, 1991

Manuscript received March 16, 1998.

Accepted in final form March 23, 1998.

Address reprint requests to: Claudia Martin, M.D., Children's Hospital, Department of Neurosurgery, 300 Longwood Avenue, Boston, Massachusetts 02115.
