Awake Craniotomy, Electrophysiologic Mapping, and Tumor Resection With High-Field Intraoperative MRI

Ian F. Parney[1], Stephan J. Goerss[1], Kiaran McGee[2], John Huston III[2], William J. Perkins[3], Frederic B. Meyer[1]

■ BACKGROUND: **Awake craniotomy and electrophysiologic mapping (EPM) is an established technique to facilitate the resection of near eloquent cortex. Intraoperative magnetic resonance imaging (iMRI) is increasingly used to aid in the resection of intracranial lesions. Standard draping protocols in high-field iMRI units make awake craniotomies challenging, and only two groups have previously reported combined EPM and high-field iMRI.**

■ METHODS: **We present an illustrative case describing a simple technique for combining awake craniotomy and EPM with high-field iMRI. A movable platter is used to transfer the patient from the operating table to a transport trolley and into the adjacent MRI and still maintaining the patient's surgical position. This system allows excess drapes to be removed, facilitating awake craniotomy.**

■ RESULTS: **A 57-year-old right-handed man presented with new onset seizures. Magnetic resonance imaging demonstrated a large left temporal mass. The patient underwent an awake, left frontotemporal craniotomy. The EPM demonstrated a single critical area for speech in his inferior frontal gyrus. After an initial tumor debulking, the scalp flap was loosely approximated, the wound was covered with additional drapes, and the excess surrounding drapes were trimmed. An iMRI was obtained. The image-guidance system was re-registered and the patient was redraped. Additional resection was performed, allowing extensive removal of what proved to be an anaplastic astrocytoma. The patient tolerated this well without any new neurological deficits.**

■ CONCLUSIONS: **Standard protocols for positioning and draping in high-field iMRI units make awake craniotomies problematic. This straightforward technique for combined awake EPM and iMRI may facilitate safe removal of large lesions in eloquent cortex.**

Key words
- Awake craniotomy
- Electrophysiologic mapping
- High-field intraoperative MRI

Abbreviations and Acronyms
EPM: Electrophysiologic mapping
iMRI: Intraoperative magnetic resonance imaging

From the Departments of [1]Neurologic Surgery, [2]Radiology, and [3]Anesthesiology, Mayo Clinic College of Medicine, Rochester, Minnesota, USA

To whom correspondence should be addressed: Ian F. Parney, M.D., Ph.D. [E-mail: parney.ian@mayo.edu]

Citation: World Neurosurg. (2010) 73, 5:547-551.
DOI: 10.1016/j.wneu.2010.02.003

*Journal homepage: **www.WORLDNEUROSURGERY.org***

*Available online: **www.sciencedirect.com***

INTRODUCTION

Awake craniotomy and electrophysiologic mapping (EPM) are established techniques to facilitate safe resection of lesions near eloquent cortex (14, 15). High-field (≥1.5 T) intraoperative magnetic resonance imaging (iMRI) is an attractive strategy to enable extensive glioma resection (2, 11). Combining EPM and iMRI would be a potent technique to facilitate safe, extensive glioma resection near eloquent cortex. This was first reported more than 10 years ago using low-field iMRI (3). However, techniques for combining EPM and high-field iMRI have only recently been described (7, 18). The delay in applying EPM to high-field iMRI may reflect the draping required to maintain a sterile field during interdissection imaging. In many high-field iMRI systems, patients' heads and upper bodies are essentially "cocooned" in sterile drapes during intradissection imaging (17). This is problematic for awake craniotomies due to issues with both patient comfort (claustrophobia for alert patients) and safety (airway protection for sedated patients). In this report, we describe a simple minimal draping technique that enables intradissection imaging to be performed easily and safely in a high-field iMRI and still maintaining sterility. This has allowed us to combine awake craniotomy and electrophysiologic mapping with high-field iMRI.

CASE REPORT

A 57-year-old right hand-dominant man presented with generalized tonic clonic seizures and one episode of transient expressive speech arrest. His neurological and general physical examination between seizures was completely normal. The MRI scans showed a large mass in his left temporal lobe. He underwent an uncomplicated stereotactic biopsy at another institution that disclosed an anaplastic astrocytoma (World Health Organization grade 3).

TECHNIQUE

Repeat MRI at our institution showed a similar tumor, although new edema was seen at the biopsy site (**Figure 1A**). A functional MRI showed bilateral activation for speech in both the frontal and temporal lobes, suggesting some language reorganization (data not shown). The patient was taken to a dedicated operating room for iMRI adjacent to a standard 1.5-T MRI scanner (General Electric, Fairfield, CT, USA) (**Figure 2A**). This system allows standard ferromagnetic tools to be used in the operating room (with the exception of the head holder, which must be nonferromagnetic). A mobile patient transfer platter attached to the operating table allows

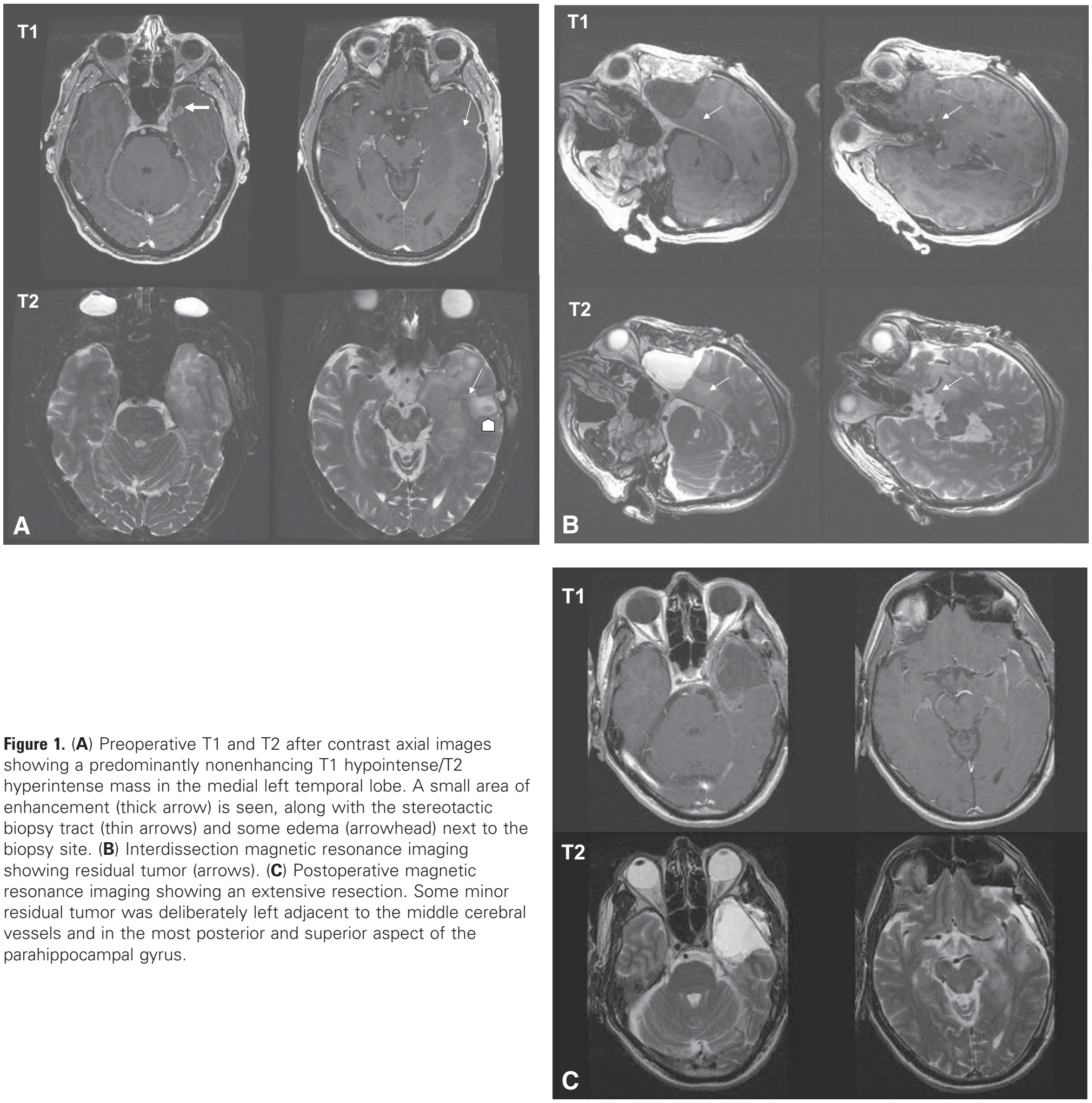

Figure 1. (**A**) Preoperative T1 and T2 after contrast axial images showing a predominantly nonenhancing T1 hypointense/T2 hyperintense mass in the medial left temporal lobe. A small area of enhancement (thick arrow) is seen, along with the stereotactic biopsy tract (thin arrows) and some edema (arrowhead) next to the biopsy site. (**B**) Interdissection magnetic resonance imaging showing residual tumor (arrows). (**C**) Postoperative magnetic resonance imaging showing an extensive resection. Some minor residual tumor was deliberately left adjacent to the middle cerebral vessels and in the most posterior and superior aspect of the parahippocampal gyrus.

the patient to be moved to a transport trolley in pinions without any change in positioning. They are transferred approximately 20 feet to the adjacent multipurpose MRI scanner for imaging before returning to the operating room. The scanning room is separated from the operating room by retractable doors.

After moderate intravenous sedation (dexmedetomidine) and generous local anesthesia (bupivacaine), he was positioned supine with a role placed under the left shoulder and the head turned slightly to the left. The head was held in place with nonferromagnetic three-point pin fixation. The preoperative MRI was registered to the patient using a STEALTH image guidance system (StealthStation, Medtronic, Minneapolis, MN, USA). This included functional MRI sequences for expressive speech. The operative field was prepped and draped in the standard fashion and a left frontotemporal craniotomy was performed. After opening the dura, the patient's sedation was lightened and electrophysiologic stimulation motor and speech mapping was performed using a 5-mm bipolar electrode as described elsewhere (14, 15). A single, critical area for speech where stimulation caused naming and counting arrest was seen in the posterior inferior frontal gyrus and marked with a sterile letter "E" ("English"; **Figure 2B**). Interestingly, this did not correlate exactly with critical areas for speech identified by functional MRI (**Figure 2C**).

An anterior temporal lobectomy extending 5 cm from the temporal pole and initial tumor debulking was performed. At the end of this procedure, a large resection cavity was created but the tumor was still present superomedially and posteriorly. The sylvian fissure had shifted 1 cm inferiorly from its position identified by STEALTH using the preoperative MRI, suggesting that image guidance was no longer accurate. Accordingly, we choose to obtain an interdissection MRI and re-register the STEALTH system. This was done to iden-

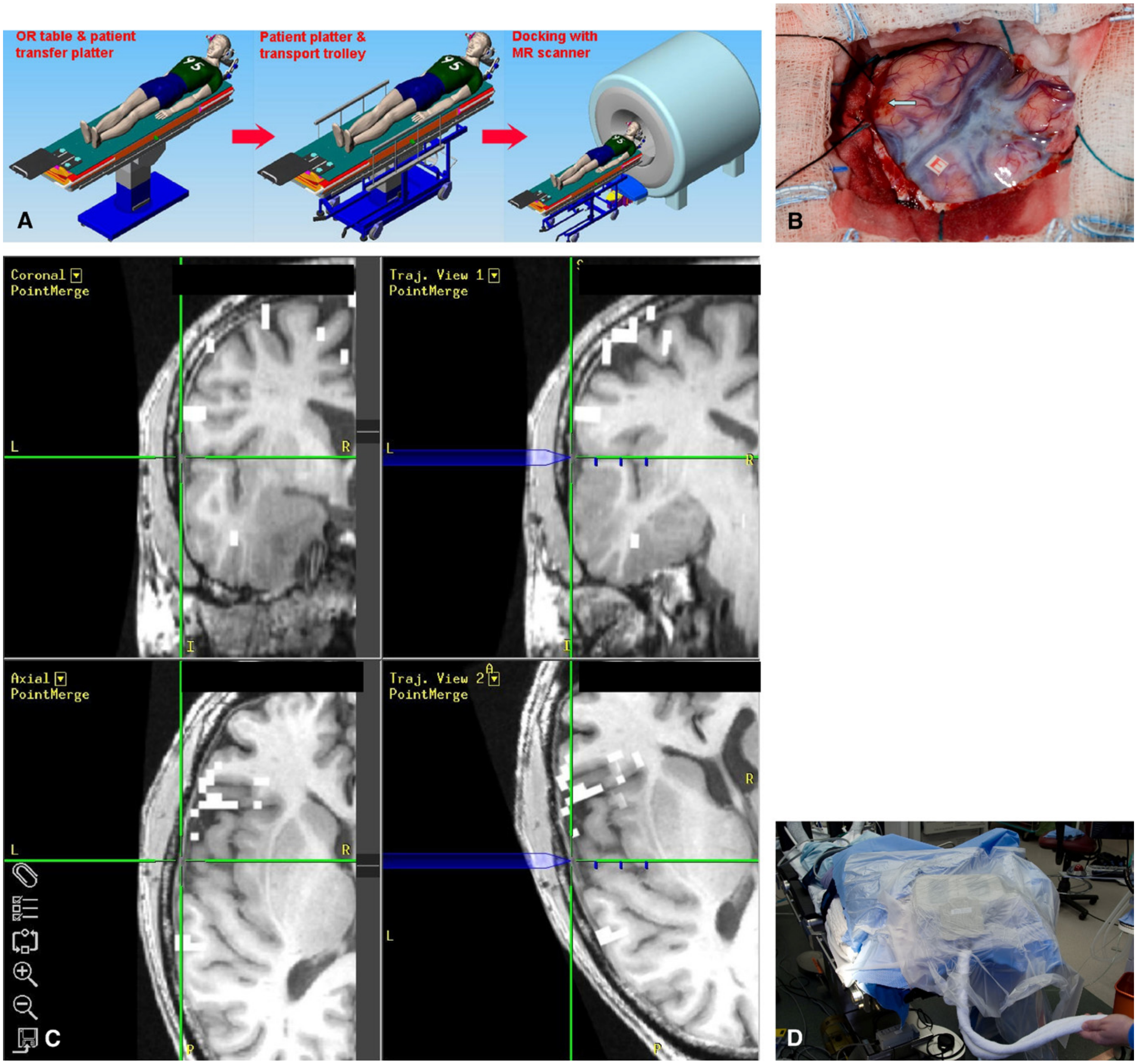

Figure 2. (**A**) Schematic showing the operating table, patient transfer platter, and transfer trolley. (**B**) Intraoperative photograph after electrophysiologic mapping. A single critical area for speech found in the inferior frontal gyrus is marked with the letter "E." The entry point for the prior stereotactic biopsy is seen in the temporal lobe (arrow). (**C**) Intraoperative screen shot from image-guidance system with probe (blue arrow) placed on the critical speech area identified by electrophysiologic mapping. Note that this is approximately 1 cm from speech areas identified by functional magnetic resonance imaging (MRI) (white pixels). (**D**) Drapes before interdissection MRI. The wound has been covered with a 60 × 60-cm sterile drape secured with a large, adhesive clear plastic drape. The anterior MRI coil has been similarly secured on top of this. Excess surrounding drapes have been trimmed to give easy access to the patient's face.

tify the exact location and extent of residual tumor and facilitate further safe image-guided resection. The scalp flap was loosely reapproximated. Sterile sponges were placed over the wound and an approximately 60 × 60-cm sterile drape was placed over the sponges and secured with a large adhesive clear plastic drape. The excess drapes were trimmed to allow the patient to be transferred to the MRI table (**Figure 2D**). The patient was kept in position with three-point pin fixation and brought into the adjacent MRI scanner using the transfer platter and transport trolley. An interdissection MRI was obtained, showing the expected residual tumor superomedially and posteromedially (**Figure 1B**). The patient was removed from the scanner and returned to the adjacent operating room where he was transferred back to the operating table, still maintaining his position with three-point pin fixation. He remained alert and comfortable throughout this imaging process. The interdissection MRI was registered to the patient using the STEALTH system. This entire process (partial closure, draping, imaging, redraping, re-registering the STEALTH system) took approximately 40 minutes.

The patient was redraped and additional resection was performed with the aid of the updated image-guidance system. Some tumor was deliberately not resected superomedially next to the middle cerebral artery and in the posterior aspect of the parahippocampal gyrus where the patient became mildly confused when we began to work in this area. Nevertheless, an extensive resection (~90%) was performed. The patient's wound was closed, he was removed from pin fixation, and a full head dressing was applied. A final postoperative MRI was obtained confirming the extent of the resection (**Figure 1C**). The patient had an unremarkable postoperative course with no new neurological deficits. The final pathological diagnosis was anaplastic astrocytoma (World Health Organization grade 3), confirming the results of his earlier biopsy sample. He has subsequently received adjuvant external beam radiation and temozolomide chemotherapy.

DISCUSSION

Penfield and Boldrey (13) first described awake craniotomy and electrophysiologic mapping more than 70 years ago. In the past 20 years, this technique has become increasingly applied for glioma resection near eloquent cortex (14, 15). Although motor mapping can be performed with patients receiving general anesthetic, speech mapping must be performed awake. Image guidance using frameless stereotaxy based on preoperative imaging is another established technique to facilitate extensive resection of intracranial lesions. This is helpful for planning craniotomies, finding lesions, and determining the extent of resection intraoperatively. Determining the extent of resection is potentially the most valuable, but is also the most challenging. As the tumor is removed, the brain shifts (6), causing significant inaccuracies to develop in image-guidance systems. This is most likely to occur in patients with large tumors (>3 cm in diameter) or tumors adjacent to the ventricles (1).

Intraoperative MRI has been proposed to help address this issue. Unlike most clinical diagnostic MRI scanners that use high-field magnets (1.5 T), the first generation of iMRI scanners used low-field magnets (0.2 to 0.5 T) (4, 8). Although useful, the image quality was reduced compared with standard MRI. As an alternative, high-field (≥1.5 T) iMRI systems have been developed that produce quality images (9, 17). Importantly, re-registering image-guidance systems with high-field iMRI appears to facilitate more extensive but safe resection compared with low-field iMRI and image guidance (2). Functional imaging, such as diffusion tensor imaging and functional MRI, can be incorporated into image-guidance systems, but brain shift makes interpretation difficult as resection proceeds and questions remain about how closely these modalities replicate EPM (the accepted gold standard) (11, 10). This was demonstrated in our patient, when the critical area for speech identified by EPM was shown to be approximately 1 cm away from any speech areas identified on functional MRI. Diffusion tensor imaging could be obtained intraoperatively to address this issue (12). It may be possible to incorporate intraoperative functional MRI for awake patients in the future as well, but this would clearly need to be balanced against the amount of time required during craniotomy.

Thus, combined EPM, image guidance, and high-field iMRI may be an ideal technique to facilitate safe extensive resection of lesions in eloquent cortex. Despite the availability of high-field iMRI for more than a decade, to our knowledge no reports combining high-field iMRI with EPM appeared in the literature until 2009 (7, 18). There may be several reasons for this, but it may reflect standard draping protocols for interdissection imaging in a high-field iMRI environment. To keep the sterile field from contamination, the patient's entire head and upper body are essentially wrapped in sterile drapes (17). This creates an environment that is either extremely claustrophobic for alert patients or potentially suffocating for sedated patients without definitive airway protection. Our simple draping technique for interdissection imaging is much less restrictive and makes awake craniotomy much less challenging. This technique is facilitated by the transfer platter and trolley that allow the patient to be transferred to and from the adjacent MRI scanner in pinions without changing the surgical position. The two earlier reports of combined EPM and high-field iMRI do not describe the draping protocols for interdissection imaging in detail, although Nabavi et al. (7) suggest uncovering the patient's face and Weingarten et al. (18) describe trimming drapes hanging below the operating table.

Additional experience with more patients and longer follow-up is necessary to definitively address outcomes for patients undergoing awake craniotomy, EPM, and glioma resection aided by high-field iMRI. The role of cytoreductive surgery in prolonging survival in patients with gliomas still remains somewhat controversial as only level 2 evidence is available at present (5, 16). Nevertheless, most neurosurgeons and neurooncologist agree that maximal safe resection is appropriate for newly diagnosed patients. We believe that simple techniques like ours for combining awake craniotomy, EPM, and high-field iMRI may be an important step in facilitating maximal safe resection for large gliomas in eloquent cortex.

REFERENCES

1. Benveniste RJ, Germano IM: Correlation of factors predicting intraoperative brain shift with successful resection of malignant brain tumors using image-guided techniques. Surg Neurol 63:542-548 [discussion: 548-549], 2005.

2. Bergsneider M, Sehati N, Villablanca P, McArthur DL, Becker DP, Liau LM: Mahaley Clinical Research Award: extent of glioma resection using low-field (0.2 T) versus high-field (1.5 T) intraoperative MRI and image-guided frameless neuronavigation. Clin Neurosurg 52:389-399, 2005.

3. Black PM, Alexander E 3rd, Martin C, Moriarty T, Nabavi A, Wong TZ, Schwartz RB, Jolesz F: Craniotomy for tumor treatment in an intraoperative magnetic resonance imaging unit. Neurosurgery 45:423-431 discussion: 431-433, 1999.

4. Black PM, Moriarty T, Alexander E 3rd, Stieg P, Woodard EJ, Gleason PL, Martin CH, Kikinis R, Schwartz RB, Jolesz FA: Development and implementation of intraoperative magnetic resonance imaging and its neurosurgical applications. Neurosurgery 41:831-842 discussion: 842-845, 1997.

5. Laws ER, Parney IF, Huang W, Anderson F, Morris AM, Asher A, Lillehei KO, Bernstein M, Brem H, Sloan A, Berger MS, Chang S: Survival following surgery and prognostic factors for recently diagnosed malignant glioma: data from the Glioma Outcomes Project. J Neurosurg 99:467-473, 2003.

6. Nabavi A, Black PM, Gering DT, Westin CF, Mehta V, Pergolizzi RS Jr, Ferrant M, Warfield SK, Hata N, Schwartz RB, Wells WM 3rd, Kikinis R, Jolesz FA: Serial intraoperative magnetic resonance imaging of brain shift. Neurosurgery 48:787-797 discussion: 797-798, 2001.

7. Nabavi A, Goebel S, Doerner L, Warneke N, Ulmer S, Mehdorn M: Awake craniotomy and intraopera-

tive magnetic resonance imaging: patient selection, preparation, and technique. Top Magn Reson Imaging 19:191-196, 2009.

8. Nimsky C, Ganslandt O, Tomandl B, Buchfelder M, Fahlbusch R: Low-field magnetic resonance imaging for intraoperative use in neurosurgery: a 5-year experience. Eur Radiol 12:2690-2703, 2002.

9. Nimsky C, Ganslandt O, Fahlbusch R: Comparing 0.2 tesla with 1.5 tesla intraoperative magnetic resonance imaging analysis of setup, workflow, and efficiency. Acad Radiol 12:1065-1079, 2005.

10. Nimsky C, Ganslandt O, Hastreiter P, Wang R, Benner T, Sorensen A, Fahlbusch R: Intraoperative diffusion-tensor MR imaging: shifting of white matter tracts during neurosurgical procedures—initial experience. Radiology 234:218-225, 2005.

11. Nimsky C, Ganslandt O, Buchfelder M, Fahlbusch R: Intraoperative visualization for resection of gliomas: the role of functional neuronavigation and intraoperative 1.5 T MRI. Neurol Res 28:482-487, 2006.

12. Nimsky C, Ganslandt O, Hastreiter P, Wang R, Benner T, Sorensen AG, Fahlbusch R: Preoperative and intraoperative diffusion tensor imaging-based fiber tracking in glioma surgery. Neurosurgery 61(1 Suppl):178-185 discussion: 186, 2007.

13. Penfield W, Boldrey E: Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. Brain 60:389-443, 1937.

14. Ojemann G, Ojemann J, Lettich E, Berger M: Cortical language localization in left, dominant hemisphere. An electrical stimulation mapping investigation in 117 patients. J Neurosurgery 71:316-326, 1989.

15. Sanai N, Mirzadeh Z, Berger MS: Functional outcome after language mapping for glioma resection. N Engl J Med 358:18-27, 2008.

16. Stummer W, Pichlmeier U, Meinel T, Wiestler OD, Zanella F, Reulen HJ: Fluorescence-guided surgery with 5-aminolevulinic acid for resection of malignant glioma: a randomised controlled multicentre phase III trial. Lancet Oncol 7:392-401, 2006.

17. Sutherland GR, Kaibara T, Louw D, Hoult DI, Tomanek B, Saunders J: A mobile high-field magnetic resonance system for neurosurgery. J Neurosurg 91: 804-813, 1999.

18. Weingarten DM, Asthagiri AR, Butman JA, Sato S, Wiggs EA, Damaska B, Hess JD: Cortical mapping and frameless stereotactic navigation in the high-field intraoperative magnetic resonance imaging suite. J Neurosurg 111:1185-1190, 2009.

received 16 July 2009; accepted 30 January 2010

Citation: World Neurosurg. (2010) 73, 5:547-551.

DOI: 10.1016/j.wneu.2010.02.003

Journal homepage: ***www.WORLDNEUROSURGERY.org***

Available online: ***www.sciencedirect.com***

Sydney Opera House. Sydney, New South Wales, Australia. Photo by David Iliff.