Arq Neuropsiquiatr 2011;69(6):949-953

Use of intraoperative MRI for resection of gliomas

Hector Navarro Cabrera[1], Antonio Nogueira de Almeida[1],
Clemar Corrêa da Silva[2], Erich Talamoni Fonoff[1], Maria das Graças Martin[3],
Claudia da Costa Leite[3], Manoel Jacobsen Teixeira[1]

ABSTRACT
Literature has shown that extent of tumor resection has an impact on quality of life and survival of patients with gliomas. Intraoperative MRI has been used to increase resection while preserving procedure's safety. **Method:** The first five patients with gliomas operated on at the University of São Paulo using intraoperative MRI are reported. All but one patient had Karnofsky Performance Status of 100% before surgery. Presentation symptoms were progressive headache, seizures, behavior disturbance, one instance of hemianopsia, and another of hemiparesis. **Results:** Gross total removal was achieved in two patients. Surgical resection was limited by tumor invasion of critical areas like the internal capsule or the mesencephalon in the remaining patients. **Conclusion:** Intra-operative MRI is an important tool that helps surgeons to remove glial tumors, however, knowledge of physiology and functional anatomy is still fundamental to avoid morbidity.
Key words: magnetic resonance imaging, glioma, brain neoplasms, neurosurgery.

Uso de ressonância magnética intraoperatória para ressecção de gliomas

RESUMO
A literatura demonstra que extensão da ressecção do tumor tem impacto na qualidade de vida e sobrevida dos pacientes com gliomas. RM intraoperatória tem sido utilizada para aumentar a área de ressecção, preservando a segurança do procedimento. **Método:** Os cinco primeiros pacientes com gliomas operados na Universidade de São Paulo utilizando RM intraoperatória são relatados. Quatro pacientes tinham índice de Karnofsky de 100% antes da cirurgia. Primeiros sintomas foram cefaléia progressiva, convulsões, distúrbios de comportamento, um caso de hemianopsia, e outro de hemiparesia. **Resultados:** A remoção macroscópica total foi obtida em dois pacientes. A ressecção cirúrgica foi limitada pela invasão tumoral de áreas críticas como a cápsula interna ou o mesencéfalo no restante dos pacientes. **Conclusão:** A RM intra-operatório é uma importante ferramenta que auxilia o cirurgião para remover os tumores gliais, porém, o conhecimento da fisiologia e anatomia funcional ainda é fundamental para evitar a morbidade
Palavras-Chave: glioma, neurocirurgia, neoplasias do sistema nervoso central, imagem por ressonância magnética.

Literature has shown that extent of tumor resection has an impact on quality of life and survival of patients with both high and low grade gliomas[1,2]. From an oncological point of view a larger removal (including all contrast enhancing area in malignant tumors) is translated into longer survival[3]. On the other hand, larger removal increases risks of neurological deficits (impairing quality of life) that may offset benefits on survival. The search of a midground between oncological and functional standpoint brings up constant debates on neurosurgical wards.

Correspondence
Antonio Nogueira de Almeida
Rua Maestro Cardim 808
01323-001 São Paulo SP - Brasil
E-mail. almeidaan@gmail.com

Conflicts of interest
The authors report no conflicts of interest

Received 17 May 2011
Received in final form 8 August 2011
Accepted 15 August 2011

[1]Department of Functional Neurosurgery, Instituto de Psiquiatria, Faculdade de Medicina da Universidade de São Paulo (FMUSP), São Paulo SP, Brazil; [2]Department of Neurosurgery, Instituto Central do Hospital das Clínicas, Faculdade de Medicina da Universidade de São Paulo (ICHC/FMUSP), São Paulo SP, Brazil; [3]Department of Radiology, ICHC/FMUSP.

Over the last decades, improvements in anesthesia, neurophysiology, and neuroimaging has given new insights in the quest for equilibrium on tumor removal[4-6].

An important achievement for neurosurgery in order to minimize brain injury related to surgical approaches for gliomas was the release of neuronavigation, however, pitfalls of the technique do exist[7]. Brain shift produced by both cerebrospinal (CSF) drainage and tumor debulking is still a major problem. Neuronavigation uses pre-operative images and, as surgery develops, anatomical landmarks on magnetic resonance imaging (MRI) become less and less reliable[8]. Intra-operative MRI turned out to be the natural solution to evaluate changes in anatomy that occur during surgery[9]. This paper focuses on our initial experience with intra-operative MRI to remove gliomas at the University of São Paulo.

METHOD

The first five patients with gliomas operated on using intra-operative MRI at the Instituto de Psiquiatria of Faculdade de Medicina da Universidade de São Paulo (FMUSP) in 2010 at the division of brain tumors from the Hospital das Clínicas of FMUSP are reported. Two members of the group (CC and HN) performed all surgeries in this series. Preoperative work up included a thorough investigation with imaging (tractography (Fig 1) and spectroscopy were used when judged necessary), and clinical evaluation by a group of neurologists, neuropsychologists, oncologists, radiotherapeuts, radiologists, and neurosurgeons at our weekly meeting.

All but one patient had Karnofsky performance status (KPS) of 100% before surgery. Presentation symptoms were progressive headache, seizures, behavior disturbance, one instance of hemianopsia, and another of hemiparesis (Table). Surgery was aimed to achieve gross total removal of tumors while preserving neurological status of patients. Two patients had gliomas infiltrating the thalamus, two had lesions involving the insula and one had a frontal recurrent glioma.

At the Instituto de Psiquiatria there is a hybrid MRI system (Siemens 1.5 Tesla). The equipment is used for both intraoperative procedures and inpatients and outpatients MRI examinations. MRI facility was placed in a room nearby the operating theater. A special door (used to transport surgical patients) separates the two areas (Fig 2).

Operating room set up includes a special surgical table in which a detachable board with a head support, Noras headholder® is mounted. Patient is positioned over the detachable board. Head is fixed on a special support that has no interference with the magnetic field (Fig 3). When necessary, the entire board is taken from the surgical room to the MRI. A head cover with fiducials is

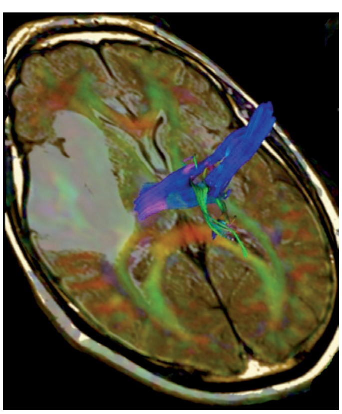

Fig 1. Pre-operative tractography showing the close relation of the internal capsule and the inner part of the tumor (patient ID 4).

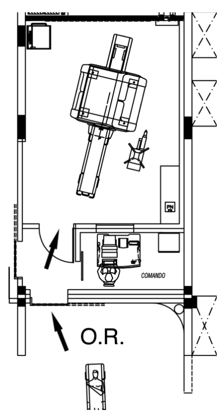

Fig 2. The MRI-OR blueprint; arrows show the path patient has to go by from OR to MRI.

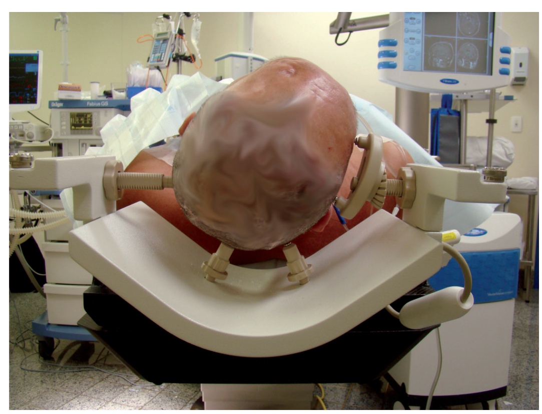

Fig 3. The special magnetic-resistant head support. Note that on the right side there is a shaft to couple the neuronavigation fiducials.

Table. Principal data of the five studied patients.

ID	Age	Tumor localization	Pre-op KPS	Neurological status
1	53	Left frontal recurrent anaplastic oligodendroglioma	90%	Right hemiparesis
2	25	Right temporo insular oligodendroglioma	100%	No deficits; focal seizures
	51	Right temporo insular gemistocitic astrocytoma	100%	No deficits; TCG seizures
4	20	Right thalamic glioblastoma multiforme	100%	Progressive headache
5	50	Right thalamic glioblastoma multiforme	100%	Left Hemi-anopsia; Behavior disturbance

ID: patient number; KPS: Karnofsky performance status; TCG: tonic-clonic generalized.

Fig 4. The special transportation table that is coupled to the head support. The cover used to protect the head also has fiducials to enable using the neuronavigation system with the new acquired images.

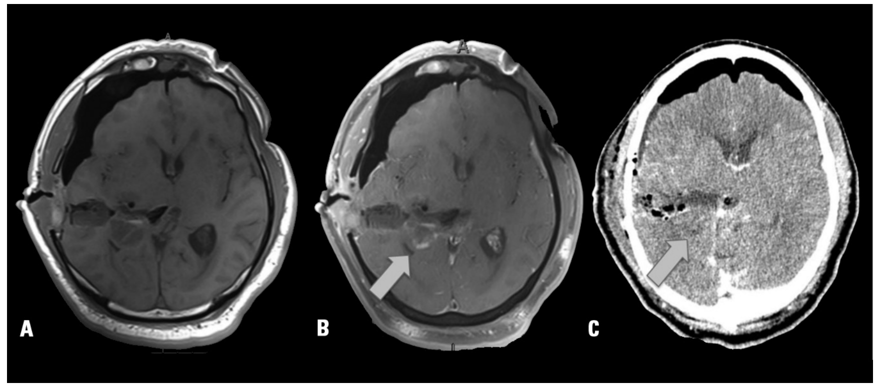

Fig 5. [A] Intraoperative MRI without gadolinium administration, [B] Gadolinium enhanced intraoperative MRI and [C] postoperative CT scan with venous constrast. Note that only the intraoperative MRI with gadolinium showed the residual contrast enhancing tumor (arrow on B). The postoperative CT using contrast was unable to show the contrast enhancing area (arrow on C) (patient ID 5).

used during intra-operative MRI acquisition in order to recalculate brain position and to allow using neuronavigation (BrainLab®) with the new images (Fig 4).

RESULTS

Operative technique followed the usual microsurgical standard. Gross total removal was achieved in two patient (ID 1 and 2). Surgical resection was limited by tumor invasion of critical areas like the internal capsule or the mesencephalon in the remaining patients. Two patients (ID 3 and 5) developed a grade IV hemiparesis after surgery. Both were discharged from hospital and were getting better on the follow up. Intraoperative MRI from patient ID 4 showed a small area of contrast close to the area of resection, which was not visible on the microscope. During procedure the surgeon chose to not further the resection fearing deficits. Though postoperative computed tomography (CT) scan did not show any contrast enhancing area, the early MRI disclosed the area involved by the tumor (Fig 5).

All imaging acquisitions occurred without any disturb in this series (Fig 6). The entire process of transporting and scanning interrupted surgery for about 50 minutes. Preparation for transportation including wound care, draping, and setting up vital sign monitoring takes about 15 minutes. Transportation proper takes about 5 minutes since patient's table has to be detached and positioned at MRI, and imaging acquisition consumes another 15 minutes. All patients undergo a T1 image with and without contrast. Other imaging acquisitions are employed based on preoperative or intra-operative findings.

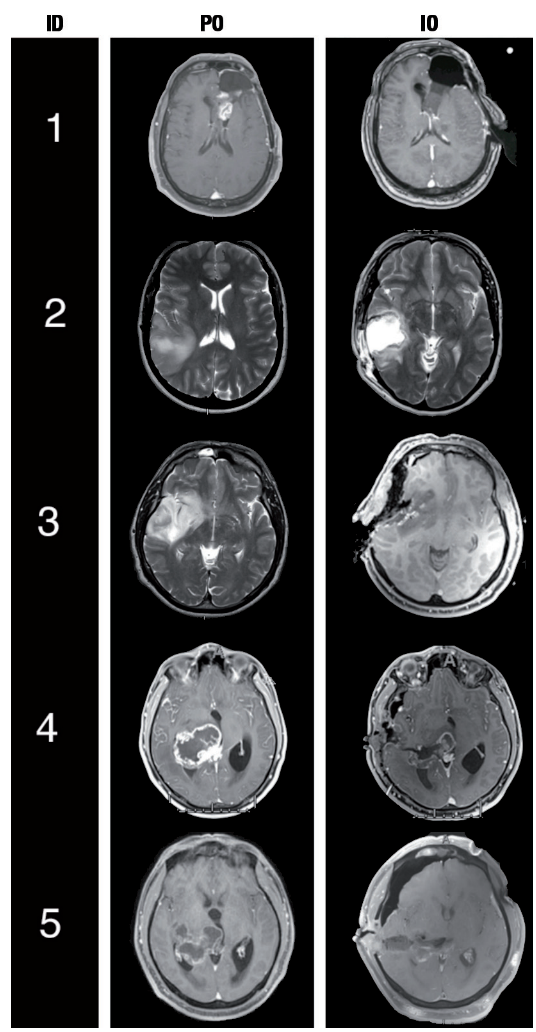

Fig 6. Preoperactive (PO) and intraoperative (IO) MRI of all patients in this series (by # on the first column). Note that image quality of intraoperative MRI is similar to the one obtained before surgery. patient 1: enhanced axial T1-weighted images, patient 2: axial T2-weighted images, patient 3: axial T2-weighted and enhanced T1-weighted images, patient 4: enhanced axial T1-weighted images, patient 5: enhanced axial T1-weighted images. ID: patient's number.

DISCUSSION

Surgery based on MRI parameters improves outcome in patients with gliomas[10]. Law et al. emphasize resection as a major factor in survival after surgery[11] while Lacroix et al. defined that only removal over 98% of contrast enhanced area affects outcome[12]. Nevertheless, other prognostic factors have to be taken into account like tumor size, patient's age, presence of neurologic deficit, and tumor crossing the midline[13]. All patients in our series were evaluated with pre-operative MRI and surgery was intended to obtain gross total removal of lesions[14], as supported by the literature[15,16]. Intra-operative MRI was used to access the amount and local of residual tumor in order to make possible its complete resection. It became critical when tumor was placed nearby structures as the thalamus or the basal ganglia. In such cases, appearance of a lesion may look like deep seated gray matter making difficult to establish a reasonable margin of resection. It should be noted that haemostatic elements (like Surgicel®) produce subtle image artifacts that may mimic blood or residual tumor[17]. In our series there was no instance of intraoperative hematoma disclosed by MRI, though, if it were the case, an early detection could avoid further complications.

Brain shift has been considered a common problem for image-guided surgery. Mathematical models have been proposed to offset intraoperative brain deformation[18]. However, our series showed that some patients did not present a significant brain shift during tumor resection. At least in two procedures, brain structure stayed almost intact during surgery. On the other hand, there was no clear-cut pre-operative data able to differentiate patients that would not evolve with brain shift. The only factor noted to be associated with little brain movement was lesions close to midline. In such cases it is likely that these structures are kept in place by the falx and dura mater from skull base.

The most common limitation of image-based resection is when tumor infiltrates primary cortical areas (like the pre central gyrus or the striate cortex) or white fibers from the corona radiata. In situations like that, gross total resection is usually not feasible without leaving a prohibitive morbidity. Most patients of this series did not have gross total removal. However, limits of tumor resection were determined by the presence of functional structures instead of the lack of acknowledgement of residual tumor. Thus intraoperative MRI was very useful to avoid unintentional injuries to brain structures in complex tumors.

Another interesting fact was that , the apparatus was able to disclose hidden contrast enhancing areas nearby surgical field, which were not visible on an early postoperative CT scan (as in Fig 4). Such a finding raises doubts about reliability of post-operative CT as the parameter for gross total removal of gliomas.

When necessary, motor areas were mapped before surgery with transcranial magnetic stimulation (TMS) or during the procedure with electrical stimulation, as reported before[19]. Unfortunately, language areas could not be mapped during surgeries using intra-operative MRI. Hybrid set up makes intra-operative MRI for awake craniotomy troublesome since the surgical field (patient's head) has to be completely covered throughout transportation and image acquisition[20]. If patient is awaken without laryngeal mask or ventilatory support, hypoventilation may be unbearable.

One aspect that deserves attention is the inaccuracy of MRI images[21]. MRI acquisition is known to generate an intrinsic and randomic deformation that need to be corrected by image overlapping (with CT scan, for instance) in order to get precision. Thus, during surgery it is essential to evaluate images taking into account anatomical landmarks. Intra-operative MRI does not preclude a thorough knowledge of anatomy. Although MRI may show the location of a residual tumor, decision to proceed with the resection must be based on surgeon's judgment considering cost/benefit of extending the surgery.

The hybrid solution for intra-operative MRI carries several benefits for our institution making it possible to scan outpatients and other inpatients outside the operative time[22]. Moreover, most surgical instruments do not need to be used on high magnetic field, reducing cost for implantation of the system. Only head support and equipment for anesthesia need to be designed to undergo magnetic field without interference. Quality of image is another advantage of the method. We have a 1.5 Tesla image while most intra-operative facilities have a 0.5 Tesla unit, which generates images of a inferior resolution[23]. Nowadays higher fields are being used mora often for intraoperative MRI[24]. One can assume that better images may bring benefits on the outcome. On the other hand, transporting patients (even for a few meters) is time consuming and carries risks that have to be weighted against the benefit of getting an image. It should be noted though that even a MRI facility far from the operating room can be viable to obtain intra-operative imaging[25]. Integration of intra-operative MRI and neuronavigation helps to decrease such a necessity. Thus each new image acquired can be used till the point surgeon feels it is not accurate enough to rely upon.

Advantages of intra-operativa MRI: [1] Quality of image is a great advantage of the method; [2] The apparatus was able to disclose hidden contrast enhancing areas nearby the surgical field, which were not visible on an early postoperative CT scan; [3] New imaging techniques (like tractography, blood vessels studies, tissue perfusion, etc) may be incorporated in order to improve surgical decisions.

Limitations of the method: [1] Some patients may present a significant brain shift during tumor resection;

[2] MRI acquisition is known to generate an intrinsic and randomic deformation that need to be corrected by image overlapping (with CT scan, for instance) in order to get precision; [3] Intra-operative imaging carries the same concerns of regular MRI regarding interference on electromagnetic implants (like heart pacemaker, drug-infusion pumps, CNS pacemakers); [4] The most common limitation of image-based resection is when tumor infiltrates primary cortical areas.

REFERENCES

1. Berger MS, Deliganis AV, Dobbins J, Keles GE. The effect of extent of resection on recurrence in patients with low grade cerebral hemisphere gliomas. Cancer 1994;74:1784-1791.
2. Quigley MR, Maroon JC. The relationship between survival and the extent of the resection in patients with supratentorial malignant gliomas. Neurosurgery 1991;29:385-388.
3. Devaux BC, O'Fallon JR, Kelly PJ. Resection, biopsy, and survival in malignant glial neoplasms. A retrospective study of clinical parameters, therapy, and outcome. J Neurosurg 1993;78:767-775.
4. Almeida AN, Tavares C, Tibano A, Sasaki S, Murata KN, Marino R Jr. Dexmedetomidine for awake craniotomy without laryngeal mask. Arq Neuropsiquiatr 2005;63:748-750.
5. Brainer-Lima PT, Brainer-Lima AM, Brandt CT, Carneiro GS, Azevedo HC. Intraoperative mapping of motor areas during brain tumor surgery: electrical stimulation patterns. Arq Neuropsiquiatr 2005;63:55-60.
6. Duffau H, Moritz-Gasser S, Gatignol P. Functional outcome after language mapping for insular World Health Organization Grade II gliomas in the dominant hemisphere: experience with 24 patients. Neurosurg Focus 2009;27:E7.
7. Willems PW, van der Sprenkel JW, Tulleken CA, Viergever MA, Taphoorn MJ. Neuronavigation and surgery of intracerebral tumours. J Neurol 2006; 253:1123-1136.
8. Wadley J, Dorward N, Kitchen N, Thomas D. Pre-operative planning and intra-operative guidance in modern neurosurgery: a review of 300 cases. Ann R Coll Surg Engl 1999;81:217-225.
9. Reinges MH, Nguyen HH, Krings T, Hutter BO, Rohde V, Gilsbach JM. Course of brain shift during microsurgical resection of supratentorial cerebral lesions: limits of conventional neuronavigation. Acta Neurochir (Wien) 2004;146:369-377.
10. Fujimura M, Kumabe T, Tominaga T, Jokura H, Shirane R, Yoshimoto T. Routine clinical adoption of magnetic resonance imaging was associated with better outcome after surgery in elderly patients with a malignant astrocytic tumour: a retrospective review. Acta Neurochir (Wien) 2004; 146:251-255.
11. Laws ER, Shaffrey ME, Morris A, Anderson FA Jr. Surgical management of intracranial gliomas--does radical resection improve outcome? Acta Neurochir 2003;85 (Suppl):S47-S53.
12. Lacroix M, Abi-Said D, Fourney DR, et al. A multivariate analysis of 416 patients with glioblastoma multiforme: prognosis, extent of resection, and survival. J Neurosurg 2001;95:190-198.
13. Pignatti F, van den Bent M, Curran D, et al. Prognostic factors for survival in adult patients with cerebral low-grade glioma. J Clin Oncol 2002;20: 2076-2084.
14. Mehdorn HM, Schwartz F, Dawirs S, Hedderich J, Dorner L, Nabavi A. High-field iMRI in glioblastoma surgery: improvement of resection radicality and survival for the patient? Acta Neurochirurgica 2011;109(Suppl): S103-S106.
15. Keles GE, Lamborn KR, Berger MS. Low-grade hemispheric gliomas in adults: a critical review of extent of resection as a factor influencing outcome. J Neurosurg 2001;95:735-745.
16. Keles GE, Lamborn KR, Chang SM, Prados MD, Berger MS. Volume of residual disease as a predictor of outcome in adult patients with recurrent supratentorial glioblastomas multiforme who are undergoing chemotherapy. J Neurosurg 2004;100:41-46.
17. Spiller M, Tenner MS, Couldwell WT. Effect of absorbable topical hemostatic agents on the relaxation time of blood: an in vitro study with implications for postoperative magnetic resonance imaging. J Neurosurg 2001;95:687-693.
18. Clatz O, Delingette H, Talos IF, et al. Robust nonrigid registration to capture brain shift from intraoperative MRI. IEEE Trans Med Imaging 2005;24: 1417-1427.
19. Amorim RL, Almeida AN, Aguiar PH, et al. Cortical stimulation of language fields under local anesthesia: optimizing removal of brain lesions adjacent to speech areas. Arq Neuropsiquiatr 2008;66:534-538.
20. Tan TK, Leong KW. Awake craniotomy in an intra-operative MRI environment. Anaesthesia 2009;64:575-576.
21. Dean D, Kamath J, Duerk JL, Ganz E. Validation of object-induced MR distortion correction for frameless stereotactic neurosurgery. IEEE Trans Med Imaging 1998;17:810-816.
22. Albayrak B, Samdani AF, Black PM. Intra-operative magnetic resonance imaging in neurosurgery. Acta Neurochir (Wien) 2004;146:543-556.
23. Foroglou N, Zamani A, Black P. Intra-operative MRI (iop-MR) for brain tumour surgery. Br J Neurosurg 2009;23:14-22.
24. Hall WA, Truwit CL. Intraoperative magnetic resonance imaging. Acta Neurochirurgica 2011;109 (Suppl):S119-S129.
25. Ramina R, Coelho Neto M, Giacomelli A, et al. Optimizing costs of intraoperative magnetic resonance imaging. A series of 29 glioma cases. Acta Neurochirurgica 2010;152:27-33.