Use of intraoperative MRI for resection of gliomas

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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 a 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 gliomas¹,². From an oncological point of view a larger removal (including all contrast enhancing area in malignant tumors) is translated into longer survival³. 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.

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Over the last decades, improvements in anesthesia, neurophysiology, and neuroimaging have given new insights in the quest for equilibrium on tumor removal\(^4\). 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 an thorough investigation with imaging (tractography (Fig 1) and spectroscopy were used when judged necessary), and clinical evaluation by a group of neurologists, neuropsychologists, oncologists, radiotherapeutists, 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 on 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

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

ID: patient number; KPS: Karnofsky performance status; TCG: tonic-clonic generalized.
used during intra-operative MRI acquisition in order to recalibrate 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 patients (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.

DISCUSSION
Surgery based on MRI parameters improves outcome in patients with gliomas. Law et al. emphasize resection as a major factor in survival after surgery while Lacroix...
et al. defined that only removal over 98% of contrast enhanced area affects outcome. 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. All patients in our series were evaluated with pre-operative MRI and surgery was intended to obtain gross total removal of lesions, as supported by the literature. Intra-operative MRI was used to access the amount and location 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 Surgical!) produce subtle image artifacts that may mimic blood or residual tumor. 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. 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. 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. If patient is awaken without laryngeal mask or ventilatory support, hypventilation may be unbearable.

One aspect that deserves attention is the inaccuracy of MRI images. MRI acquisition is known to generate an intrinsic and random deformations 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. 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 inferior resolution. Nowadays higher fields are being used more often for intraoperative MRI. 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. 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 random 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