"Extraoperative" MRI (eoMRI) for Brain Tumor Surgery: Initial Results at a Single Institution

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BACKGROUND: **There is accumulating evidence that extent of resection (EOR) in intrinsic brain tumor surgery prolongs overall survival (OS) and progression-free survival (PFS). One of the strategies to increase EOR is the use of intraoperative MRI (ioMRI); however, considerable infrastructure investment is needed to establish and maintain a sophisticated ioMRI. We report the preliminary results of an extraoperative (eoMRI) protocol, with a focus on safety, feasibility, and EOR in intrinsic brain tumor surgery.**

METHODS: **Ten patients underwent an eoMRI protocol consisting of surgical resection in a conventional operating room followed by an immediate MRI in a clinical MRI scanner while the patient was still under anesthesia. If findings of the MRI suggested residual safely resectable tumor, the patient was returned to the operating room. A retrospective volumetric analysis was undertaken to investigate the percentage of tumor resected after first resection and if applicable, after further resection.**

RESULTS: **Six of 10 (60%) patients were thought to require no further resection after eoMRI. The EOR in these patients was 97.8% ± 1.8%. In the 4 patients who underwent further resection, the EOR during the original surgery was 88.5% ± 9.5% ($P = 0.04$). There was an average of 10.1% more tumor removed between the first and second surgery. In 3 of 4 (75%) of patients who returned for further resection, gross total resection of tumor was achieved.**

CONCLUSION: **An eoMRI protocol appears to be a safe and practical method to ensure maximum safe resections in patients with brain tumors and can be performed readily in all centers with MRI capabilities.**

INTRODUCTION

There is growing evidence that the extent of resection (EOR) in intrinsic brain tumor surgery prolongs overall survival (13, 17) and progression-free survival (PFS); in cases of low-grade gliomas, it may even deter their transformation to high-grade tumors (3, 19). One of the strategies to increase EOR is the use of intraoperative MRI (ioMRI) (11, 12, 18). As one of the first institutions to implement ioMRI, we have had a significant experience in the use of this imaging modality to assist with surgical resections of intrinsic brain tumors (6). The implementation of clinical ioMRI, however, requires considerable investment in infrastructure and personnel (4). This may not be practical for all centers doing brain tumor surgery, especially in the current health care climate. Furthermore, even in centers featuring a functioning ioMRI suite, the demand to use such a suite not uncommonly exceeds the capacity of the ioMRI to accommodate all brain tumor surgeries. In this scenario, a complementary method of using MRI during surgery to assess extent of resection may be additive.

To ensure that all patients receive the benefit of immediate high quality perioperative imaging guidance for maximum EOR, we have recently implemented an "extraoperative" MRI (eoMRI) protocol. This protocol (described herein), consists of transporting patients to a nearby clinical MRI scanner after maximum safe resection was felt to have been accomplished and before extubation, if the case was done under general anesthesia, or full

Key words
- Brain tumor
- Magnetic resonance imaging
- Surgery

Abbreviations and Acronyms
eoMRI: Extraoperative magnetic resonance imaging
EOR: Extent of resection
GTR: Gross total resection
ICU: Intensive care unit
ioMRI: Intraoperative magnetic resonance imaging
MAC: Monitored anesthesia care
MRI: Magnetic resonance imaging
OR: Operating room
PFS: Progression-free survival

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Citation: World Neurosurg. (2015). http://dx.doi.org/10.1016/j.wneu.2015.02.002

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

awakening if done under monitored anesthesia care (MAC). If during eoMRI it was thought that a greater extent of safe resection could be accomplished, patients are transported back to the operating room (OR). Otherwise, they are awakened in the intensive care unit (ICU). We report below preliminary results of this eoMRI protocol, with a focus on safety, feasibility, and EOR in intrinsic brain tumor surgery.

METHODS

The study was performed under the supervision of the Partners Health Care and Brigham and Women's Internal Review Board. Adult patients that were seen by the senior author (I.D.) and were consented for possible eoMRI and second resection. Intraoperatively, if the senior author thought that immediate feedback about the EOR was important, patients were included in the study. This was based upon tumor location, imaging characteristics and whether the ioMRI suite was available.

This protocol consists of patients receiving standard of care preoperative imaging and intraoperative neuronavigation, microsurgical, and ultrasonography-guided resection. Patients were induced in the usual fashion with the sedative, propofol 1.5–2.5 mg/kg, and vecuronium, a nondepolarizer muscle relaxant to facilitate endotracheal intubation. The anesthetic was maintained with total intravenous anesthesia consisting of propofol 75–200 μg/kg/min and remifentanil 0.10–0.20 μg/kg/min throughout the procedure depending on the level of surgical stimulation. Neuromonitoring was used commonly to assess motor-evoked and somatosensory-evoked potentials if sensorimotor tract integrity was a concern. Two patients were performed while awake under MAC for intraoperative language assessment.

After the surgeon has completed what is thought to be the maximum resection, the craniotomy is closed in standard manner. At the time of closure, the clinical MRI suite is alerted so as to make sure that there is no wait time between closure and imaging. The patient remains intubated or under MAC, is ventilated with a portable ventilator if necessary, and is transported to a nearby clinical MRI suite, where the he or she undergoes a predefined MRI protocol (discussed later) to assess for tumor residual. We currently maintain sterility in the OR, even after the patient leaves, in anticipation that they might return on the basis of imaging findings, as outlined in the sections to follow.

During transport, all patients are monitored with a 5-lead electrocardiogram, a pulse oximeter, and invasive blood pressure measurement via a radial artery catheter. The transport general anesthetic was maintained with propofol 50–75 μg/kg/min and remifentanil 0.1 μg/kg/min. MRI safety procedures prohibit the introduction of standard MRI-unsafe portable ventilators and intravenous pumps into the scanner room. As such, the patient must be switched to an MR-safe ventilator before he or she enters the MR scanner room. Although it is acceptable to also switch the patient to an MRI safe intravenous pump before bringing the patient into the scanner room, to save time compared with switching the pump, in our institution the patient's intravenous tubing was rerouted from the portable intravenous pump outside the scanner room through wave-guides in the MR room shielding. This requires that the Henora (Henora Gainesville, Florida, USA) 360 inch coiled MRI extension intravenous set be used, which is of sufficient length and compatible in the MR homogenous field.

With the use of a clinical 1.5-T MRI, a variety of MRI sequences are run, depending on the original imaging characteristics of the tumor. The sequences that are required to decide whether further resection is necessary are run first. These sequences are reviewed on the scanner console without interrupting the MRI acquisition protocol. With the aid of an attending neuroradiologist, a decision is made whether maximum safe resection has been achieved. If it is thought that there may be residual tumor that is safe for resection, the scan is stopped and the patient is returned to the operating suite for further resection (see **Figure 1** for a detailed flowchart). If needed, an additional navigation sequence may be acquired before the patient is removed from the scanner and is used for re-registration upon reoperation. If in the surgeon's judgment a complete resection or maximal safe resection has been achieved, the remainder of a standard postoperative MRI is completed before the patient is transferred to the ICU for extubation or full awakening.

Volumetric Analysis

Semiautomated and manual 3D volumetric analysis was done retrospectively via commercially available software (iPlan Cranial Version 3.0.3, Brainlab AG, Westchester, Illinois, USA). For tumors with a significant contrast-enhancing component, the enhancing tumor volume was measured preoperatively, extraoperatively and postoperatively. For nonenhancing tumors, the volume of tumor on fluid-attenuated inversion recovery T2-weighted images was segmented manually.

RESULTS

Between January 2012 and December 2013, 10 patients underwent eoMRI protocol. **Table 1** summarizes the preoperative clinical characteristics of the patients. Technically successful eoMRI was achieved in all 10 patients enrolled (**Table 2**). Of these patients, 4 (40%) were assessed to have residual tumor that could be safely resected after their first stage resection and were taken back to the operating suite for a completion of their resection (**Table 2**). In the patients deemed to have a good initial stage resection that did not warrant a second-stage operation, the percentage of tumor removed was 97.8 ± 1.8%, whereas in those returning for a second-stage resection, the percentage of tumor removed was 88.5 ± 9.5% ($P = 0.04$) (2-tailed Student t test) during their first stage surgery (**Figures 2** and **3**). All 4 patients who were taken for second surgery had preoperative imaging demonstrating only slight (1 patient) or no (3 patients) contrast enhancement on T1-enhanced imaging and hyperintensity on fluid-attenuated inversion recovery T2-weighted imaging. All 4 of these patients had final pathology of Grade II or III glial tumors.

The average time between second incision and time of out of the room from the first surgery was 1.6 ± 0.2 hours, which includes time for transport, MRI, and re-draping and prepping the patient. The average time for the second surgery was 1.7 ± 0.2 hours. For the patients who underwent further resection, there was an average of 10.1% more tumor removed between the first and second surgery. In 3 of 4 (75%) of cases that returned for further resection, there was a gross total resection (GTR) achieved.