Intraoperative MRI for Glioma Surgery: Present Overview and Future Directions

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OVERVIEW OF INTRAOPERATIVE MAGNETIC RESONANCE IMAGING

Intraoperative magnetic resonance imaging (iMRI) was introduced in 1994 with the 0.5 Tesla (T) "double donut" magnet that surrounded the operating table.[1] Surgeons operated within the confines of a narrow space between the 2 halves of the magnet; however, although this provided the opportunity to easily obtain repeated scans during surgery, it provided limited access to the patient.[1] Other early iterations of iMRI included a low-field (0.15T) movable magnet that could be situated beneath the operating table and moved into position to acquire images.[1] Subsequently, iMRI technology has evolved considerably. Most current iMRI devices employ 1.5T or 3T high-field magnets that do not impede patient access. These iMRI devices are either moved into the operating room on a ceiling-mounted track or are located in close proximity to the surgical field so that the patient can be transferred to the magnet in the same room or an adjacent room for imaging as needed.[1]

iMRI can provide high-resolution images for neurosurgical procedures that can be acquired in near real-time in specially equipped suites. Naturally, this lends itself well to brain tumor surgeries for which maximal safe resection is the optimal goal. Tumor resection can be complicated by a number of factors, including brain shift or other surgical changes that may be difficult to predict or visualize. Using iMRI, the surgeon can pause mid-case and acquire images to identify areas of residual tumor or to further clarify important structures. Moreover, iMRI can enhance frameless stereotactic neurosurgical navigation. Intraoperative images can be fused with preoperative images using the stereotactic navigation software to better understand alterations of anatomy during surgery.

Despite its potential advantages, iMRI implementation requires a significant financial investment for hospitals, alterations to operating rooms, and uniquely trained staff to ensure safe operation of these complex devices. As such, research into the utility and accuracy of iMRI is paramount to discern the true impact of this technology. Two randomized control trials have been conducted to evaluate the impact of iMRI for glioma surgery,[2,3] which have demonstrated that iMRI may significantly increase extent of resection (EOR) and rates of gross total resection (GTR). Several retrospective studies have also shown that iMRI may help increase EOR for both low- and high-grade gliomas compared to surgeries that did not use iMRI.[4,5]

The authors of this article have conducted many retrospective multicenter studies examining the impact of iMRI on outcomes after glioma resection.[6-8] These studies have found that iMRI increased EOR, which was positively associated with longer overall survival and progression-free survival. In this way, iMRI may be a useful tool for prolonging survival. For grade II astrocytomas and oligodendrogliomas, for instance, additional tumor resection after iMRI was performed in 66% of cases that utilized iMRI, of which GTR was obtained in nearly 55% of these cases.[7] Use of iMRI was also significantly associated with increased progression-free survival on multivariate regression.

For glioblastoma, the authors used volumetric tumor analyses to compare surgical resections that were conducted with and without iMRI. They determined that additional resection facilitated by iMRI led to a 6.3% mean increase in EOR for tumors with initial subtotal resection.[6] EOR was also higher in iMRI groups regardless of whether the surgeon had initially intended a subtotal resection or a GTR. Further studies (unpublished) are examining the role of iMRI for ependymomas and pilocytic astrocytomas. In addition, the authors found iMRI to be a reliable tool for discerning residual tumor during glioma surgeries. For grade I—IV gliomas, histopathological samples of tumor specimens acquired from additional resections after iMRI were positive for residual tumor in 89%—93% of cases.[9] As shown in multiple studies, iMRI-guided increases in EOR can be achieved without higher rates of postoperative neurologic deficits.[4-6]

FUTURE DIRECTIONS

Despite evidence touting the benefits of iMRI for glioma resection, iMRI use is mainly informed by surgeon or institutional preferences and the variable availability of this technology. Surgeons often have differing views on the utility of iMRI for resection of gliomas. More research is needed to examine the opinions and preferences of surgeons regarding iMRI use to provide a cross-sectional view of how iMRI is utilized and to elucidate for which tumors it may be the most useful. Such investigations, combined with more prospective studies examining the impact of iMRI, would better define whether iMRI should be incorporated into standard of care for certain tumors or tumor locations.

Other areas in need of further investigation include optimization of image capture with iMRI. Current iMRI devices can perform both standard (e.g., T1, T2, fluid attenuated inversion recovery, diffusion-weighted imaging) and more "advanced" sequences (e.g., perfusion, diffusion tensor imaging [DTI], resting-state). To date, the benefit and scope of intraoperative imaging using advanced sequences have been examined in less detail. Intraoperative DTI, for instance, has been used to accurately identify corticospinal tracts and how these fibers may shift during tumor resection, but this is not common practice. Intraoperative identification of other white matter tracts such as optic radiations, arcuate fasciculus, or beyond with DTI could also be incorporated into iMRI paradigms. The same may be true for the role of other advanced imaging techniques such as resting-state images acquired during glioma resection. Continued exploration of the combination of iMRI and other imaging technologies such as fluorescent imaging with 5-aminolevulinc acid (5-ALA) or intraoperative ultrasound is needed as well because using multiple tumor imaging modalities in tandem may safely and synergistically increase EOR.[10]

Finally, an emerging benefit of iMRI has been the facilitation of laser interstitial thermal therapy (LITT). This technique involves stereotactic insertion of a laser probe into a tumor or other lesion and intensively heating the lesion while using magnetic resonance thermography to assess the extent of "tumor kill." Increases in the availability of iMRI suites have advanced the application of LITT in the treatment of gliomas, and iMRI will remain integral as the indications for LITT expand for many more neurosurgical conditions.

In summary, iMRI has enabled great advances regarding the surgical management of gliomas, and this technology likely will have an expanding role in the future of neurosurgery. However, more data on how best to apply iMRI will help properly tailor its use.

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