Editorial

Intraoperative Magnetic Resonance Imaging in Neurosurgery

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Neurosurgeons since time immemorial have been in search of an ideal navigational tool, which can help them plan, localize a lesion, and provide real-time guidance. Development of image-guided navigation systems improved the localizing ability, but major drawback of these systems was absence of real-time guidance. After craniotomy, tumor decompression, or cerebrospinal fluid (CSF) release, there is brain shift. Conventional navigation systems work on preoperatively acquired images of computed tomography scan (CTS) or magnetic resonance imaging (MRI). Preoperative data can usually help a surgeon plan and localize a lesion, but during surgery its utility is limited. Intraoperative imaging is required to update and recalibrate the navigation system to account for the brain shift. This can be done using ultrasound (USG), CTS, or MRI. USG is a cheaper alternative than the other two, but the quality of imaging is inferior. Moreover, it is a user-dependent technology. Similarly, CTS cannot discern brain tumor interface in all patients. Therefore, its utility for brain tumor surgery is limited. MRI provides excellent quality of images. It can help surgeons in improving their extent of resection (EOR) by targeting the residual lesion after acquiring intraoperative scan. The other advantage of intraoperative MRI (iMRI) is avoidance of nonionizing radiation. Because of these reasons, research and developments in this field happened at a faster pace. The Departments of Neurosurgery and Radiology of the Brigham and Woman's Hospital at Harvard Medical School in Boston and the General Electric Medical System developed the first iMRI in 1991. In 1994, the first prototype was installed at the Brigham and Woman's Hospital. It was a 0.5 Tesla MRI system with a doughnut-type magnet in which a gap was left between the coils of the magnet for the surgeon to stand and position the patient.[1] This had its own share of disadvantages, as MRI-compatible operative instruments, microscopes, and anesthesia machines were required. Realization of the fact that ergonomics of patient and surgeon's positioning for complex and long surgeries is more important than continuous need for MRI led to further developments. Siemens came up with the concept of "twin operating theater," where surgery will be performed in one suite and then the patient can be transported to other room. Thus, surgery could be performed with usual instruments. However, the first magnet used for such "twin room theater" was a 0.2 Tesla field of Magnetom Open system. The disadvantages of this system included increased duration of surgery due to 20 to 40 minutes being utilized in transportation of the patient, poor-quality images from 0.2 Tesla magnet, and higher installation costs as two separate rooms had to be built.[2]

Sutherland in 1999 developed a suite, which allowed surgery to be performed in a standard operating room (OR) while magnet was stored separately in a closed-door room. This ceiling mounted magnet could be brought into the OR, whenever needed. The magnet utilized was a 1.5 Tesla one and it provided high-quality images. However, this required placement of a radiofrequency tent over the patient and parts of the operating table before scanning is done.[3]

Hall et al[4] developed a 1.5 Tesla MRI system that was placed in a shielded OR. Surgeries could be performed using normal instruments beyond the 5 Gauss line, and the patient could be moved into the fixed scanner. They also developed an area behind magnet where surgery could be performed using MRI-compatible instruments.

Siemens and Brainlab collaborated to develop another concept in which MRI machine is fixed; the patient is operated beyond the 5 Gauss line on a table that can be rotated. The whole OR is integrated with seamless image transfers between Siemens console and Brainlab's navigation. Screens placed in OR can be utilized for projection of images, navigation, or ongoing surgery.[2] The All India Institute of Medical Sciences, New Delhi, has this system (►**Fig. 1**). The advantage includes seamless workflow and decreased time in transportation. However, the utility of the magnet is limited, and it cannot be utilized for diagnostic purposes when the surgery is going on. Moreover, the table has many electric and mechanical components that are calibrated in relation to the MRI, and their malfunctioning has occasionally hampered our surgeries. Many centers in India have opted for twin- or three-room concept where MRI is separate and can be utilized for diagnostic purposes as well. This improves the cost-effectiveness of installing such an expensive machine.

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Fig. 1 Intraoperative MRI operating room (“Brain Suite”) at the All India Institute of Medical Sciences, New Delhi. Swivel table can be rotated for shifting patient into gantry, when intraoperative MRI is required. Patient can be operated, beyond the 5 Gauss line (depicted in red color) by usual neurosurgical instruments.

Historically, Boston group led the way for iMRI’s use in glioma surgery.[5] Heidelberg group in a later series have clearly documented iMRI’s usefulness in optimizing cytoreduction during glioma surgery.[6] Functional navigation and intraoperative high-field MRI (1.5 Tesla) were first used by Erlangen group, and they have also documented additional resection in a series of 47 cases, in which nonidentifiable tumor remnants were initially left. In 36% cases, iMRI led to further continuation of surgery, thus leading to improved EOR.[7] Heidelberg group has reported that the EOR was same when experienced surgeons were compared with less experienced surgeons. In their series of 224 patients, they have reported that in 70% cases they had to continue surgery after the initial MRI. The additional resection after MRI did not lead to more neurologic deficits. Thirty-seven (16.5%) patients had minor or severe permanent deficits. These results are comparable with existing reports in literature.[8] Senft et al[9] have also reported increase in EOR in a randomized trial, in which iMRI utility has been demonstrated. In our initial experience of using iMRI, we have reported “iMRI increased the EOR in 59.7% (40/67) of patients who underwent iMRI.”[10]

Hughes Duffau from Montpellier and Mitch Berger from San Francisco have advocated awake craniotomy for intraoperative functional mapping and preserving function. There is no doubt that the use of this technique is helpful in preservation of function, but it comes at a cost of larger craniotomies. Moreover, larger EOR may not be possible.[6] We believe that this technique is best when lesion is in eloquent cortex and iMRI is not available. However, if iMRI is available, equally good functional outcomes can be obtained when functional MRI is utilized for identifying eloquent cortex along with use of direct electric stimulation. Samii et al have reported similar findings in their experience of more than 600 patients.[6] We regularly utilize functional imaging and direct stimulation in our setup. In our experience of more than 400 patients (unpublished), we find this technique is very good for obtaining higher EOR when preservation of motor tracts is needed. However, for speech-related functions, awake craniotomy is best. Doing awake craniotomy in iMRI is slightly more difficult. Painting, draping, and shifting patient in the gantry for MRI can be a challenging task. A sleep–awake–sleep pattern of anesthesia might be a more suitable option while performing awake craniotomy in iMRI.

Despite the advances in the field of endoscopy, which provides improved visualization of pituitary tumors, incidence of residual tumor can lead to potential complications. iMRI can help in improving the EOR and thus decreasing the incidence of complications related to residual disease. Zaidi et al[11] have shown that iMRI helped them in converting 12 (60%) gross total resections (GTRs) to 16 (80%). Szerlip et al[12] have reported in their series of 59 cases of pituitary adenoma operated using iMRI guidance that iMRI helped in improving EOR from 40 to 72% and 55 to 88% for tumors of the sella with and without suprasellar extension, respectively.

We conducted a randomized trial for pituitary adenoma to establish the utility of this technology. We have shown that in 25% cases, iMRI helped in improving the EOR. Moreover, by using this technology younger surgeons could validate their results intraoperatively, and hence could increase EOR without causing any increase in complications[13] (►**Fig. 2**).

The quality of MRI images has been steadily improving. Diffusion tensor imaging helps in identifying the tracts, functional imaging helps in localizing the eloquent cortex, and perfusion imaging may help in identifying more malignant areas of the tumors. No other imaging technique (USG or CTS) provides comparable images. In the years to come, in the developed countries, the use of this technology will fast become a standard of care for resection of gliomas and pituitary tumors. The cost-effectiveness of this technology is not known. Certainly, iMRI is an expensive gadget, and in a country such as India, its use may be more suitable in tertiary care or apex centers. Wherever available, we recommend its use for glioma and pituitary surgery. Expansion of iMRI usage will happen when ergonomics related with positioning of the patient are improved and installation costs are substantially reduced.

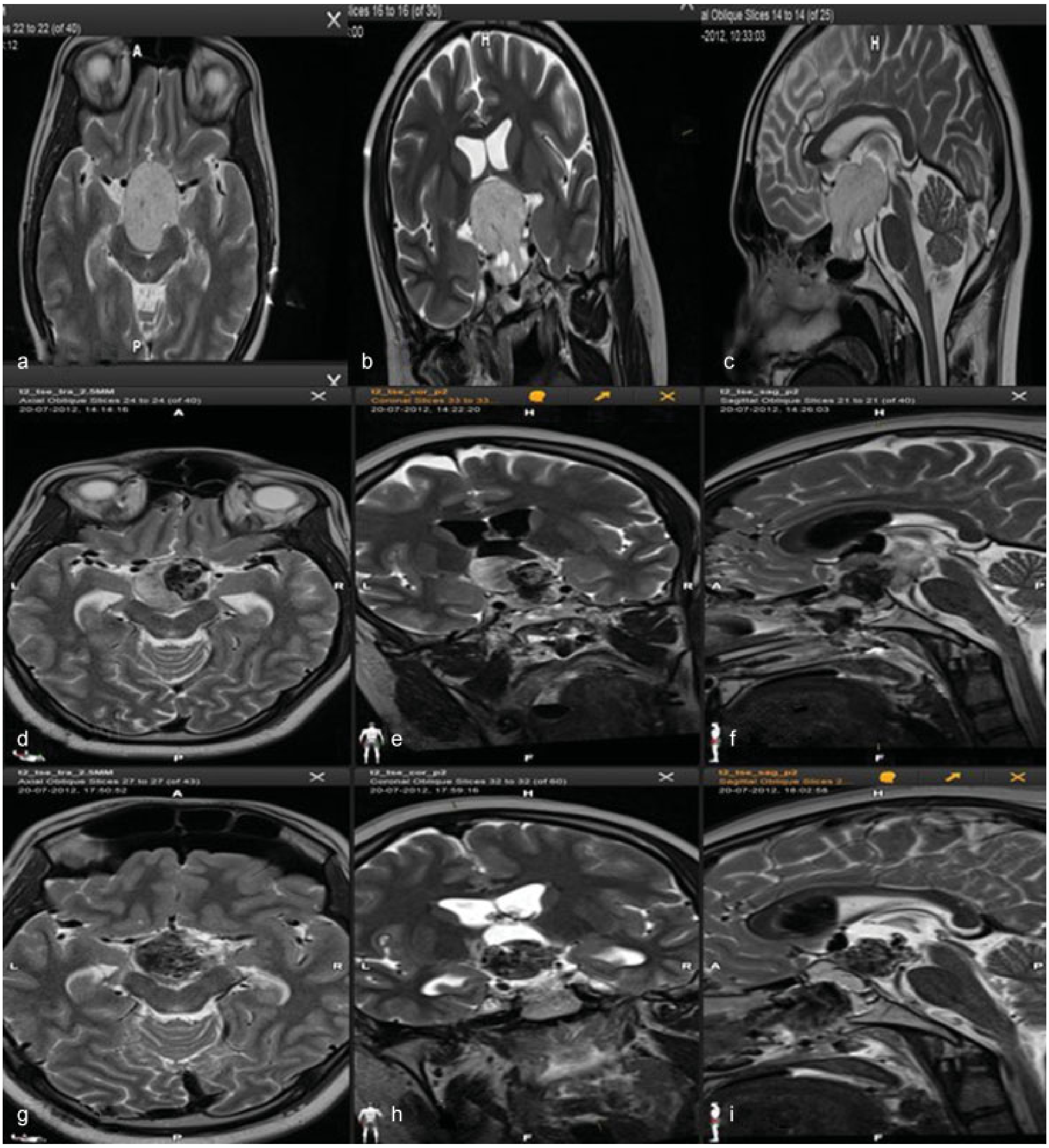

Fig. 2 Utility of intraoperative imaging in a case of pituitary adenoma. (**a–c**) Preoperative images of a patient with pituitary macroadenoma. (**d–f**) Intraoperative images showing residual tumor in the sellar region. (**g–i**) Postoperative images showing gross total excision of the tumor.

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