Magnetic resonance imaging and deep brain stimulation

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The past decade has seen a considerable broadening of the role of intraoperative MR imaging in neurosurgery. The added benefit of high-resolution MR imaging during operations to remove brain tumors, resect epileptogenic tissue, and address intramedullary spinal cord lesions among other procedures is becoming increasingly well-established.1,6 Ironically, functional neurosurgery using frame-based or frameless stereotaxy—whose evolution has long paralleled advances in brain imaging including MR imaging—has conspicuously lagged behind other neurosurgical subspecialties in adopting intraoperative MR imaging. In their paper, “Intraoperative magnetic resonance imaging findings during deep brain stimulation surgery,” Huston et al.5 present the first substantial series of patients who underwent surgery for deep brain stimulator implantation aided by intraoperative MR imaging.

This is a sizeable study from a large center with considerable experience in deep brain stimulation (DBS) surgery. In their protocol, the authors scanned patients with a 1.5-T intraoperative magnet at 2 specific time points during otherwise standard, frame-based stereotactic DBS procedures: 1) immediately prior to scalp opening for target selection and trajectory planning; and 2) immediately following electrode implantation—but prior to implantable pulse generator internalization—to confirm correct final electrode position and screen for hemorrhagic complications. An MR imaging physicist was present during all scans to ensure that MR imaging safety standards were followed while imaging implanted electrodes, while neuroradiologists contributed to selecting MR sequences suited to detecting postoperative blood. Over a period of nearly 4 years, the authors performed 152 DBS procedures aided by intraoperative MR imaging, comprising 289 individual electrode implantations. In their experience, intraoperative MR imaging confirmed correct electrode placement in all cases, while identifying 9 cases of hemorrhage, only 1 of which produced transient clinical symptoms. In addition, intraoperative MR imaging demonstrated a high incidence of brain shift due to pneumocephalus.

Assuming it can be done safely—which Huston et al.5 have convincingly demonstrated—the most obvious advantage of intraoperative MR imaging applied to DBS surgery is that it permits immediate verification of correct electrode position after placement. Naturally, this instant feedback gives functional neurosurgeons the opportunity to make corrective modifications during a single surgical procedure, avoiding the risks and inconvenience of a delayed return to the operating room. Virtually all centers performing DBS surgery employ some form of postoperative imaging for quality assurance, and a very strong argument can be made that such imaging should be done while the patient is still on the operating table. This is especially true for surgeons choosing to implant electrodes via a purely image-guided approach without microelectrode recording (MER).3,9

A secondary advantage afforded by intraoperative MR imaging is the early identification of patients who have sustained an intracranial hemorrhage due to DBS insertion. Flagging these patients—as in this study—for close monitoring in the postoperative period, ideally in an intensive care unit, may help prevent unanticipated and potentially disastrous deterioration caused by expanding hematomas. Furthermore, using intraoperative MR imaging obviates the need for postoperative CT scanning with its associated dose of ionizing radiation. The DBS-compatible imaging sequences employed by the authors are clearly sensitive and specific to the presence of blood in intraparenchymal, subarachnoid, and subdural compartments, and together make up a practical imaging protocol that can be used in any center with access to intraoperative MR imaging.

Strictly speaking, Huston et al.5 have applied intraoperative MR imaging in a rather elementary fashion to DBS surgery, essentially moving conventional pre- and postoperative scanning from the radiology department into the operating room. While this application offers the obvious theoretical benefits mentioned above, it raises 2 additional questions: 1) whether using intraoperative MR imaging in this way really improves outcomes in DBS surgery; and 2) whether intraoperative MR imaging might be applied differently during DBS procedures, with the potential for as yet unforeseen benefits. With its retrospective methodology, lack of a control group undergoing DBS unaided by intraoperative MR imaging, and the absence of any measure of clinical efficacy at follow-up, this study simply cannot answer the first question. If anything, the authors did not need to modify the position of even a single electrode after intraoperative MR imaging may argue against routine use of the technology. It is worth mentioning that a 100% rate of satisfactory electrode placement is itself notable and unexpected. No
doubt it is largely related to the authors’ technique and experience, but it would be useful to know how they defined an acceptable electrode position, whether they observed any differences between planned and final electrode coordinates, and if any electrodes had to be moved in a delayed fashion due to poor benefit from stimulation or due to side effects.

The authors pose an answer to the second question by speculating that intraoperative MR imaging might eventually eliminate the need for MER. Unfortunately, they make this statement with neither an appropriate explanation nor the support of any compelling data. In this series, MER was used in every case but we are not told the average number of tracks per patient, how MER influenced final electrode position, or, most importantly, how intraoperative MR imaging could conceivably have altered the use of MER. Logically, it would seem that any decision to abandon MER must necessarily take into account the quality of preimplantation imaging, the degree to which such imaging faithfully reproduces actual brain anatomy, and the ability of the neurosurgeon to identify the target accurately on preoperative images, none of which have anything to do with whether a patient undergoes imaging inside or outside the operating room.

A missed opportunity to apply intraoperative MR imaging in this study relates to the issue of brain shift, which the authors identified in over 80% of their cases. Recent published reports have concluded that brain shift during DBS surgery may produce inaccuracies in accurate electrode placement.\(^2,8,10\) In particular, shifts occurring during implantation of the first electrode in a bilateral procedure may predispose the patient to malposition of the second (contralateral) electrode.\(^4\) Consequently, in bilateral cases, it would have been instructive if MR images had been acquired after implanting the first electrode before proceeding to the opposite side, with the aim of reassessing the accuracy of the original target and modifying it if necessary. Simply presenting the mean shift seen at the end of each case, as the authors do, fails to capture how brain shift impacted the procedure. Furthermore, these mean shift values are difficult to interpret, being neither assigned a direction nor qualified in relation to standard internal reference points such as the anterior or posterior commissures.

Intraoperative MR imaging is now more accessible to the functional neurosurgeon than ever. With their series, Huston et al.\(^3\) show that it can be applied safely within certain constraints in patients undergoing DBS electrode implantation, and suggest—but fall short of convincingly proving—how the technology could improve the care of these patients. No doubt more reports will be forthcoming from other institutions documenting their own experiences with intraoperative MR imaging; these data will better define its role in DBS surgery. As with any technology, enthusiasm about new applications must always be tempered by careful considerations of efficiency, cost, and above all, safety. Safety is particularly relevant given the unlikely but real possibility of serious injury when scanning patients with implanted electrodes, as well as in light of the emergence of 3T intraoperative MR imaging scanners, whose higher field strength, according to DBS manufacturers, precludes safe scanning.? Given the multitude of issues that remain to be resolved, it seems that with intraoperative MR imaging and DBS, the real debate is just getting started.

Disclosure

The authors report no conflict of interest.

References


Response

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We would like to thank Drs. Sankar and Lozano for their thoughtful comments on our manuscript. An important finding in this study is that MR imaging can be performed safely in patients with DBS electrodes in place within the intraoperative setting. The pulse sequences that we have employed—T1 magnetization-prepared rap-