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The Neurosurgical Operating Room of the Future: Has the Future Arrived?

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solid evidence that the findings of mesial temporal sclerosis are significant in the clinical setting of epilepsy. The sample size, however, is neither large nor diverse enough to predict the true significance of these findings in the general population.

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The Neurosurgical Operating Room of the Future: Has the Future Arrived?

In the rapidly changing world of neurosurgery, image guidance has gained an increasing role in a wide range of surgical procedures. These techniques include frameless and frame-based stereotactic guidance, intraoperative computed tomography, and, most recently, intraoperative MR imaging. The goals of these methods have included guidance to the site of an abnormality, reduction of the necessary craniotomy size, and avoidance of damage to nearby critical structures.

During the past several years, a number of series have been published describing the utility of intraoperative MR imaging guidance for neurosurgical procedures (1–4). These have suggested many benefits derived from the excellent soft-tissue contrast resolution and near-real-time scan acquisition of intraoperative MR imaging. In addition to the capabilities of conventional stereotactic techniques, intraoperative MR imaging can also guide surgery in the presence of changing levels of brain shift, document the completeness of tumor resection, and monitor the development of intraoperative complications such as hemorrhage while the craniotomy remains open. Although several of these prior reports have described large numbers of patients, the evidence of clinical usefulness has remained largely anecdotal. In order to promote more widespread clinical acceptance of intraoperative MR imaging, and to justify the associated equipment costs, more scientific proof of the effectiveness of this technology and impact on patient outcome is necessary.

The article by Knauth et al in this issue of the *AJNR* (page 1642) is a highly significant first step toward the scientific proof of efficacy. In this prospective investigation, the authors studied 41 neurosurgical procedures performed with a neuronavigation system based on preoperative MR data. When the operating neurosurgeon believed that all enhancing tumor had been removed, an intraoperative MR imaging set was obtained on a 0.2-T system. Further resection was performed, if necessary and feasible, until all enhancing tumor visible on intraoperative MR images had been resected. After surgery, an early postoperative MR imaging examination at 1.5-T was performed. The authors document a highly statistically significant increase in the success of complete resection of enhancing tumor through the addition of intraoperative MR data, increasing from under 37% after stereotactic neuronavigation alone to over 75% after the addition of intraoperative MR imaging information.

Documentation of the ability to provide more complete resection of enhancing tumor is an essential step toward the acceptance of intraoperative MR imaging techniques into the mainstream neurosurgical community. Nevertheless, before intraoperative MR imaging is accepted as a standard of neurosurgical care, proof of improved patient outcome will be necessary.

With this in mind, the choice of resection of high-grade gliomas as an initial clinical application must be examined, as extension of tumor beyond the enhancing margins is well documented for these tumors. For this reason, this investigation by Knauth et al may be most significant as a proof of concept rather than as a recommendedation of therapy for high-grade glioma. The conclusions of their investigation suggest that the use of this technology for intraoperative monitoring and guidance during resection of low-grade gliomas, metastases, and other better-localized intracranial lesions through the use of intraoperative MR imaging might also significantly benefit the patient. It is these applications, for which complete tumor resection is not only possible but can result in cure, that likely will further drive the dissemination of intraoperative MR imaging technology. There may also be some benefit in improving resection for high-grade glioma. Several neurosurgical series, referenced in the article by Knauth et al, suggest that patient survival or a progression-free interval or both is increased when removal of all enhancing tumor is possible.

An additional issue that merits discussion is the time needed to obtain intraoperative MR images. In this report by Knauth et al, intraoperative imaging required approximately 25 to 30 minutes of scan time and 30 to 35 minutes of setup time. Clearly, if this extra hour of procedure time eliminates the need for repeat craniotomy, it is acceptable. This long imaging time, however, limited in-

traoperative scanning to a single session with the technique reported by these authors.

Other methods have been described that increase the number of times that MR images can be readily obtained during surgery in order to monitor and guide the procedure more closely. Setup time can be almost eliminated by performing surgery within the scanner, as reported by the group at Brigham and Women's Hospital (1). At our institution, we use the same 0.2-T imaging system as described by Knauth et al, but reduce patient positioning and scan setup to under 2 minutes by performing surgery adjacent to the scanner on a rotating operating table (5, 6). By modification of scan parameters, we also decrease imaging times to approximately 2½ minutes for T1-weighted images and 3½ minutes for T2-weighted images, without a significant decrease in observable image quality (6). This allows us to obtain images at much more frequent intervals during the surgical procedure.

The time required for image acquisition can also be reduced by performing MR imaging at higher field strength, as recently reported with intraoperative imaging at 1.5-T by the group at University of Minnesota (4). Other techniques with more rapid patient positioning and shortened scan times have also been described at several other institutions, and can allow a marked reduction in the added procedure time necessary for intraoperative MR imaging. It is likely that the proportion of patients in whom complete resection was attained would have been further increased had Knauth and colleagues been able to repeat intraoperative MR imaging without unreasonable lengthening of the surgical procedure.

In summary, intraoperative MR imaging is still a young technology and has only recently taken its first scientific steps toward maturity. Its bright future, however, will undoubtedly be illuminated further as others build on this excellent work of Knauth et al.

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Line-Scan Diffusion Imaging of Term Neonates with Perinatal Brain Ischemia

In this issue of the *AJNR*, Robertson and colleagues (page 1658) describe and interpret their findings from line-scan diffusion imaging studies of 12 neonates with diffuse perinatal ischemic injury and seven neonates with perinatal cerebral infarction. The authors found that diffusion-weighted imaging is more sensitive than T1- and T2-weighted spin-echo images, nearly always showing an abnormality in the early post-injury period. They found, however, that even diffusion imaging is sometimes falsely negative. In addition, they reported that the extent of injury is nearly always underestimated by the initial diffusion imaging study. This article raises a number of interesting points, all of which cannot possibly be addressed fully in a short editorial. We will, therefore, focus on only a few issues: the choice of imaging techniques in the asphyxiated neonate; timing of the imaging; regional variations in maturation of the brain; differences in occlusive versus nonocclusive ischemia; and the physiologic interpretation of diffusion measurements.

In a recent issue of the *AJNR*, the topic of choices of imaging studies in asphyxiated term neonates was addressed (1). The author suggested that sonography was the best initial choice because it is portable and inexpensive, but that this technique has well-recognized limitations and is often unrevealing. MR imaging was judged to be the best technique in spite of its insensitivity to early damage. Two relatively new MR imaging techniques, diffusion-weighted imaging and proton spectroscopy, seem to have overcome the problem of lack of early sensitivity. Diffusion imaging shows a reduction in apparent diffusion coefficient within 15 minutes of injury. Proton spectroscopy shows elevation of lactate within a few hours. Both of these time frames are well within the window of opportunity for medical intervention to reduce potentially severe brain damage. Many potential treatments have been shown to reduce neonatal hypoxic-ischemic brain damage in animal models, including hypothermia, neurotropins, growth factors, calcium channel blockers, antioxidants, anti-inflammatory agents, and glutamate antagonists (2). Can we use these new techniques to detect injury in all neonates with a difficult delivery and any evidence of