The predictive value of low–field strength magnetic resonance imaging for intraoperative residual tumor detection

Clinical article

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Object. Neurosurgeons have been utilizing intraoperative MR (iMR) imaging to evaluate the extent of tumor resection since the 1990s. A low–field strength (0.12 T) MR imaging unit (PoleStar N20, Medtronic) is a practical and relatively inexpensive iMR imaging system that has found increased use in neurosurgery. The gold standard for postoperative detection of residual tumor has been high-strength MR imaging performed within 48 hours of resection. The object of this study was to determine the predictive concordance of low-strength iMR imaging with standard high-strength MR imaging for detection of residual tumor.

Methods. The authors retrospectively evaluated the MR images from 74 intracranial tumor resections, comparing the intraoperative images obtained using a 0.12-T iMR imaging unit to the immediate postoperative images obtained using a standard 1.5-T MR imaging unit within 48 hours after surgery.

Results. The sensitivity of low-field MR imaging for detection of residual tumor was 0.74 (95% CI 0.58–0.86), and its specificity was 0.97 (95% CI 0.83–1). When only glial tumors (42 of the 74 lesions) were analyzed, the sensitivity was 0.82 (95% CI 0.59–0.94) and the specificity was 0.95 (95% CI 0.73–1).

Conclusions. These data could assist the neurosurgeon who has to decide intraoperatively whether the observed iMR images show residual tumor or not. (DOI: 10.3171/2008.9.JNS08729)

Key Words • intraoperative MR imaging • low–field strength intraoperative MR imaging • sensitivity • specificity

Abbreviation used in this paper: iMR = intraoperative MR.
Intraoperative tumor detection by MR imaging represent residual tumor or not. It would thus be helpful for the neurosurgeon to know the accuracy of such low-field images in terms of detection of residual tumor as compared with the “gold standard” of postoperative high–field strength imaging performed within 48 hours of surgery.

In an attempt to answer this question, we retrospectively reviewed our experience in 74 cases of intracranial tumors in which low-strength iMR imaging was used to determine the presence or absence of residual tumor and evaluated the concordance of this imaging with the “gold” standard of postoperative imaging. Our results show that low-strength iMR imaging can detect residual tumor, but there is some error when the results of the iMR imaging are compared with the findings of postoperative MR imaging performed within 48 hours of surgery. These data may be of assistance to the neurosurgeon who has to decide intraoperatively on the likelihood of observed iMR images detecting the presence or absence of residual disease.

Methods

Patient Population

We retrospectively identified 72 patients who underwent resection of 74 intracranial tumors with the aid of 0.12-T iMR imaging (PoleStar N20, Medtronic) between the dates of April 2005 and February 2008. The numbers of tumor by type are shown in Table 1. Within 48 hours of surgery, patients underwent a routine postoperative MR imaging examination performed with a 1.5-T unit.

Operative Procedure and Imaging

Patients were brought to the operating room and an iMR imaging study was performed before skin incision. The types of images varied, depending on tumor type and operation. For example, for enhancing supratentorial nonellar tumors, the imaging sequences most commonly obtained were axial T1-weighted sequences with Gd enhancement, using the Polestar N20 T1 axial 3-mm 1-minute protocol. For sellar masses, coronal and sagittal T1-weighted sequences with Gd enhancement using the Polestar T1 axial 3-mm 1-minute protocol were most commonly obtained. For nonenhancing supratentorial tumors, axial FLAIR (FLAIR 4-mm 9-minute protocol) and/or T2-weighted (T2 4-mm 13-minute protocol) sequences were obtained. To minimize external interference, a copper wire tent (StarShield, Medtronic) was used during iMR imaging. An additional set of images was obtained when the neurosurgeon believed that the surgery was completed. In general, the same types of images were obtained as those obtained preoperatively. We also tried to ensure that the patient and table were not moved during surgery to optimize comparison of the images obtained before and after surgery. For contrast enhancement, 10–15 mg/kg Gd was administered intravenously about 5 minutes before image acquisition. Rarely, the surgeon had to return to the operative field to remove additional tumor on the basis of the iMR images. Postoperative images were obtained within 48 hours of surgery using standard MR imaging with a 1.5-T unit (GE Healthcare).

<table>
<thead>
<tr>
<th>Category</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>oligodendroglioma (Gr II and III)</td>
<td>21</td>
</tr>
<tr>
<td>pituitary adenoma</td>
<td>19</td>
</tr>
<tr>
<td>astrocytoma IV (GBM)</td>
<td>14</td>
</tr>
<tr>
<td>astrocytoma III (anaplastic)</td>
<td>5</td>
</tr>
<tr>
<td>meningioma</td>
<td>3</td>
</tr>
<tr>
<td>epidermoid</td>
<td>2</td>
</tr>
<tr>
<td>ganglioglioma</td>
<td>2</td>
</tr>
<tr>
<td>low-grade astrocytoma</td>
<td>2</td>
</tr>
<tr>
<td>DNET</td>
<td>1</td>
</tr>
<tr>
<td>metastatic lesion</td>
<td>1</td>
</tr>
<tr>
<td>glioneuronal tumor</td>
<td>1</td>
</tr>
<tr>
<td>cerebellar dysplasia</td>
<td>1</td>
</tr>
<tr>
<td>craniopharyngioma</td>
<td>1</td>
</tr>
<tr>
<td>ependymoma</td>
<td>1</td>
</tr>
</tbody>
</table>

* DNET = dysembryoplastic neuroepithelial tumor; GBM = glioblastoma multiforme; Gr = Grade.

Data Analysis

At the time this study was conducted (during the first few months of 2008), we compared the postoperative images with the intraoperative MR images to determine concordance or absence of concordance. The study did not use the intraoperative interpretation of residual tumor because, several times, the neurosurgeon was unsure of the interpretation (see Introduction of this paper). As an additional test, we also compared their read of the postoperative MR imaging that was found to be in agreement to that made by several neuroradiologists that provided an impression of presence or absence of residual tumor using the images from the routine postoperative MR imaging over the 4-year period of use of iMR imaging. The neuroradiologists were not privy to the intraoperative images and thus were essentially blinded. Relevant postoperative images from the postoperative 1.5-T MR imaging studies were compared only to the last iMR images to determine if the evidence of residual tumor present in the latter was confirmed in the former. Only the last iMR image obtained after the surgeon had decided that additional resection was not warranted was used for the comparison. Intermediate images obtained before additional tumor resections were not used. The relevant images consisted of axial T1-weighted Gd-enhanced images for enhancing, nonellar tumors; coronal T1-weighted Gd-enhanced images for sellar tumors; and axial FLAIR or T2-weighted images for nonenhancing tumors. The preoperative images obtained using the iMR imaging unit and/or preoperative standard MR images were also compared with the last set of iMR images and/or postoperative standard MR images to confirm the presence of an area of residual tumor. Residual tumor was defined as presence of nodular enhancement on the final iMR or postoperative 1.5-T MR images for enhancing lesions or the presence of
nodular or bulky FLAIR or T2 abnormality on the final iMR or postoperative 1.5-T MR images that was clearly within the volume of FLAIR or T2 abnormality on the preoperative study. Linear enhancement on the final iMR or postoperative 1.5-T MR images or “fuzzy” enhancement on the final iMR images that was outside the area of preoperative enhancing tumor volume was not considered residual tumor. Similarly, areas of FLAIR or T2 abnormality on the final iMR images that were not present within the original FLAIR or T2 abnormality on the initial iMR images were not considered residual tumor, but rather intraparenchymal abnormality associated with the surgical procedure.

**Statistical Analysis**

The prevalence, specificity, and sensitivity were calculated by using the Vassar calculator program (http://faculty.vassar.edu/lowry/clin1.html).

**Results**

**Categorization of Cases**

After each comparison between the last iMR imaging study and the 1.5-T postoperative MR imaging study, the 74 cases were placed into 1 of 4 categories:

**Category A.** This “true negative” category included those cases where the 0.12-T iMR images and postoperative standard 1.5-T MR images were concordant with respect to the absence of residual tumor (Fig. 1); 46% of the cases studied were in this category.

**Category B.** This “true positive” category included those cases where the iMR images and postoperative standard MR images were concordant with respect to the presence of residual tumor (Fig. 2); 39% of cases were in this category.

**Category C.** This “false negative” category consisted of cases in which the iMR images did not appear to show residual tumor, but residual tumor was evident on the postoperative standard MR images (Fig. 3); 14% of cases were in this category.

**Category D.** This “false positive” category consisted of cases in which the last iMR imaging study was thought to show residual tumor, but on postoperative standard MR images no residual tumor was identified (Fig. 4); 1% of all cases in this study were in this category.

**Sensitivity and Specificity Analysis**

The prevalence of residual tumor in all the cases studied and the sensitivity and specificity of iMR imaging for detection of residual tumor are illustrated in Table 2. For all tumors, the sensitivity of iMR imaging (ability to detect residual tumor) was 0.74, while the specificity (ability to confirm that no residual tumor existed) was 0.97. Thus, for any particular case, the probability that the last iMR images will be positive for residual disease would be 0.41 (95% CI 0.29–0.53) and the positive predictive value (true positive) would be 0.97 (95% CI 0.81–1.0), whereas the negative predictive value (true negative) would be 0.77 (95% CI 0.62–0.88). When only glial tumors were considered (that is, after exclusion of pituitary tumors, meningioma, and metastases), the above values did not change much (Table 3), with a sensitivity of 0.82, a specificity of 0.95, a positive predictive value of 0.95 (95% CI 0.73–1), and negative predictive value of 0.83 (95% CI 0.59–0.94).

**Discussion**

Intraoperative MR imaging technology is being used more frequently primarily as an adjunct to guiding more complete tumor resections. Multiple iMR imaging technologies are now available and a low–field strength MR (0.12 T) has been marketed and used at multiple locations worldwide. Proponents of low-strength MR imaging cite its practicability, relative low cost, relative ease of execution, and relative safety due to the low magnet strength. However, available literature is unclear on how sensitive and specific low-strength iMR imaging is in detecting residual tumor when compared with the current gold stan-
Intraoperative tumor detection by MR imaging

A postoperative 1.5-T MR imaging study performed within 48 hours of surgery. The results of this analysis seem to indicate that 0.12-T iMR imaging detects residual tumor, when present, with a sensitivity of at least 74% and can confirm absence of tumor, when not present, with a specificity of 97%. When only glial tumors were considered, the sensitivity improved to 82% and the specificity was 95%.

In 15% of the cases there was disagreement between the iMR images and postoperative MR images. In 14% of cases, the iMR images did not show residual tumor although tumor was evident in the standard postoperative MR images. Reasons for this failure included technical problems (the final iMR images were not interpretable, the machine failed due to “noise;” or Gd enhancement was poor) or issues inherent with the technology (iMR image thickness missed tumor or there was poor resolution due to low field strength and/or limited field of view). While this disagreement seems a possible reason for concern, one may argue that the absence of the iMR imaging technology would not have prevented the neurosurgeon from leaving residual tumor, since the images are generally collected when the surgeon believes that the tumor has been resected. In these cases, the iMR images provided confirmation of the surgical impression, albeit falsely. In these 14% of “false negative” cases, the neurosurgeon would have stopped tumor resection on the basis of surgical impression with or without the iMR images. Stated in another way, the addition of iMR imaging did not add or detract from the intraoperative decision that the tumor had been resected.

More concerning were the 1% of cases in which the iMR images appeared to detect residual tumor, but there was no evidence of residual tumor on standard postoperative images. These “false positive” cases could lull the neurosurgeon into thinking that more tumor needs to be removed and thus guide him or her into adjacent

TABLE 2: Detection of residual tumor by iMR imaging versus postoperative MR imaging in 74 surgical cases*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Residual Tumor on 1.5 T Postop MRI (no. of cases)</th>
<th>Estimated Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual tumor detected on 0.12 T iMRI (test positive)</td>
<td>29</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>No residual tumor detected on 0.12 T iMRI (test negative)</td>
<td>34</td>
<td>10</td>
<td>44</td>
</tr>
<tr>
<td>Prevalence of residual tumor</td>
<td>0.53</td>
<td>0.41–0.64</td>
<td></td>
</tr>
<tr>
<td>Sensitivity of iMRI</td>
<td>0.74</td>
<td>0.58–0.86</td>
<td></td>
</tr>
<tr>
<td>Specificity of iMRI</td>
<td>0.97</td>
<td>0.83–1.0</td>
<td></td>
</tr>
</tbody>
</table>

* Sensitivity and specificity values are given for iMR imaging relative to the gold standard of postoperative 1.5 T MR imaging.
TABLE 3: Detection of residual tumor by iMR imaging versus postoperative MR imaging in 42 cases of glial tumors*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Residual Tumor</th>
<th>Estimated Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual tumor detected on 0.12-T iMRI (test positive)</td>
<td>18</td>
<td>0.52</td>
<td>0.37–0.68</td>
</tr>
<tr>
<td>No residual tumor detected on 0.12-T iMRI (test negative)</td>
<td>19</td>
<td>0.82</td>
<td>0.59–0.94</td>
</tr>
<tr>
<td>Prevalence of residual tumor</td>
<td>0.95</td>
<td>0.73–1.0</td>
<td></td>
</tr>
</tbody>
</table>

* Sensitivity and specificity values are given for iMR imaging relative to the gold standard of postoperative 1.5 T MR imaging.

Conclusions

This retrospective analysis shows that the sensitivity and specificity of detection of residual tumor by using intraoperative low-field strength MR imaging may be acceptable. Because this information is not currently available in most centers, it could add knowledge to the intraoperative decision related to extent of tumor resection. Intraoperative high-field strength magnets may be able to improve the sensitivity and specificity of residual tumor detection.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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References

Intraoperative tumor detection by MR imaging