The Utility of Intraoperative Magnetic Resonance Imaging in the Resection of Cerebellar Hemispheric Pilocytic Astrocytomas: A Cohort Study

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BACKGROUND: The mainstay of treatment for cerebellar pilocytic astrocytomas in the pediatric population is surgery. The use of intraoperative magnetic resonance imaging (iMRI) as a surgical adjunct may lower the likelihood of reoperation. Studies have examined iMRI in heterogenous tumor populations, but few have looked at single pathologies.

OBJECTIVE: To compare iMRI vs non-iMRI for hemispheric cerebellar pilocystic astrocytomas, specifically looking at revision surgeries and residual disease in follow-up.

METHODS: Retrospective review of medical records for 60 sequential patients with cerebellar hemispheric pilocytic astrocytoma at a single institution was conducted. Thirty-two patients with cerebellar pilocytic astrocytoma underwent surgery without iMRI, whereas 28 patients underwent surgical resection with iMRI. All patients had at least 3-year follow-up.

RESULTS: There were no significant differences between the patient populations in age, tumor size, or need for cerebrospinal fluid diversion between groups. Operative time was shorter without iMRI (without iMRI 4.4 ± 1.3 hours, iMRI 6.1 ± 1.5, $P = .0001$). There was no significant difference in the patients who had repeat surgery within 30 days (9% without iMRI, 0% iMRI, $P = .25$), residual disease at 3 months (19% without iMRI, 14% iMRI, $P = .78$), or underwent a second resection beyond 30 days (9% without iMRI, 4% iMRI, $P = .61$). There were more total reoperations in the group without iMRI, although this did not reach significance (19% vs 4%, $P = .11$).

CONCLUSION: For hemispheric cerebellar pilocytic astrocytomas, iMRI tended to leave less residual and fewer reoperations; however, neither of these outcomes achieved statistical significance leaving utilization to be determined by the surgeon.

KEY WORDS: Pilocytic astrocytoma, Intraoperative MRI, Posterior fossa tumor, Pediatric brain tumors, Surgical outcomes, Case series

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The tools used for brain tumor resection have evolved significantly over the past century. Examples of which include the use of operating microscope, image guidance, and fluorescence tumor marker just to name a few. One of such tools is the intraoperative magnetic resonance imaging (iMRI), which provides immediate imaging feedback on the extent of resection, theoretically increasing the likelihood of gross total resection (GTR) with a single surgery. As many centers have now used iMRI for more than a decade, many studies have been written to evaluate the surgical outcomes. However, most of the current literature on the use of iMRI include heterogenous tumor pathologies and locations, which directly influence resectability, decision-making intraoperatively, and duration of follow-up period.[1-4] As a result, the usefulness of iMRI for any particular lesion cannot be easily extrapolated from these studies.

In this study, we restricted our patient population to a single anatomic location and a single pathology: hemispheric cerebellar pilocytic astrocytomas. The tendency for this tumor to displace, not invade, brain tissue lends itself to a safe GTR in most cases (Figure). When it is achieved, excellent long-term prognoses, without

ABBREVIATIONS: GTR, gross total resection; **iMRI,** intraoperative magnetic resonance imaging.

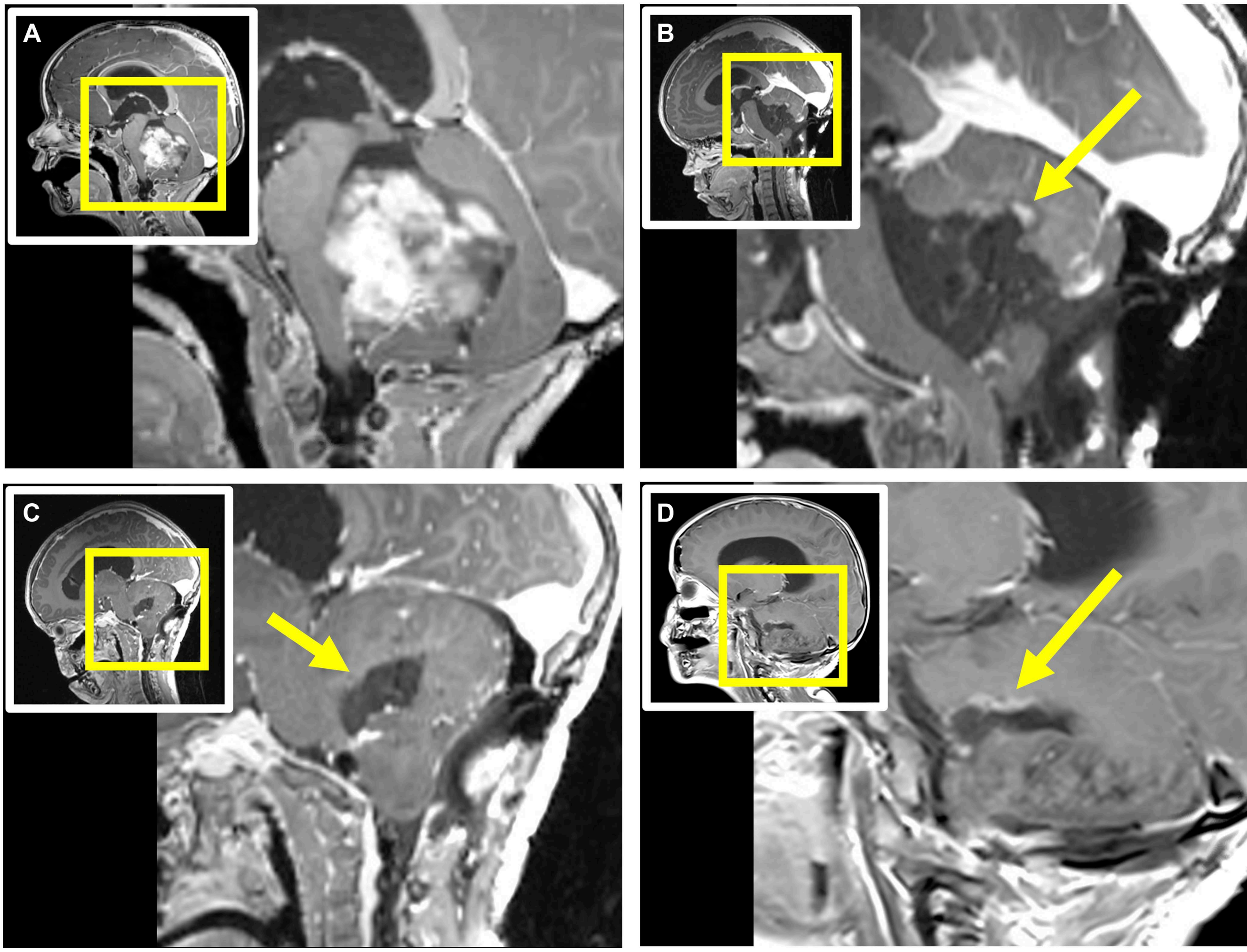

FIGURE. **A**, *Example of a cerebellar pilocytic astrocytoma in the sagittal view on magnetic resonance imaging with contrast.* **B**, *Intraoperative scan reveals a small area of residual along the superior resection cavity, hidden by overhanging tissue.* **C**, *Intraoperative scan showing a clean resection along the anterior-superior border without enhancement.* **D**, *Postoperative scan (POD2) showing a thin rim of enhancement along that area that could be mistaken for residual had not the intraoperative scan confirmed this was clean.*

the need for adjuvant therapies, are the norm.[5,6] As a result, surgery remains the foundation of all treatment plans for cerebellar pilocytic astrocytomas.[7] In this relatively homogenous patient population, we sought to elucidate whether the use of iMRI would significantly change the incidence of residual tumor or rate of reoperation, both in the short term and long term after the index resection.

METHODS

A retrospective case series review of medical records at this institution identified 60 consecutive patients with cerebellar pilocytic astrocytoma undergoing surgery between 2007 and 2012. Approval was obtained from our institutional review board for data collection, including waiver of patient consent because of the retrospective design. Patients were excluded from the study if younger than 2 years because of limitations compatibility between the infant head fixation device and the MRI. A minimal follow-up of 3 years was deemed necessary because pilocytic astrocytoma is an indolent disease. The follow-up period was defined as time from the initial surgery to the most recent MRI.

A 1.5T iMRI (IMRIS) was installed in 2009 at one of our 2 pediatric surgical centers. Before then, all patients underwent resection without iMRI at both centers. All surgeons have access to schedule cases at the iMRI-capable center, so after installation in 2009, the decision to use iMRI was based on which center the patient was at, availability of that OR, and the surgeon's preference. When iMRI was used, intraoperative imaging was reviewed by a board-certified neuroradiologist in real time and results were communicated to the operating neurosurgeon directly.

TABLE 1. Patient and Tumor Characteristics

Patient characteristic	Non-iMRI	iMRI	*P*-Value
Total patients	32	28	
Average age (yr)	7.8 ± 4.0	9.3 ± 4.1	.15
Symptom duration (wk)	8	11	.33
Preoperative EVD (No. of patients)	11	11	.81
Intratumoral hemorrhage	6	4	1.00
Cystic tumor (%)	71	82	.38
Tumor size (cm^3)	58 ± 37	61 ± 50	.77
Tumor location (distance from the midline, mm)	8.1 ± 6.9	7.6 ± 6.9	.76

EVD, external ventricular drain; iMRI, intraoperative magnetic resonance imaging. Where reported, average ± standard deviation.

Based on that information, the neurosurgeon would determine whether further resection is needed. If further resection was performed, the option is available to conduct a second iMRI scan.

Medical records were reviewed for relevant patient information. This included the patient's age, sex, and clinical findings on presentation, such as increased intracranial pressure or focal neurological deficits. Radiographic findings were documented including tumor dimensions, presence or absence of a cystic component, and the distance of the center of tumor bulk to the midline. Ventricular caliber was assessed with measurements of the third ventricle and calculation of the frontooccipital horn ratio, in addition to documentation of transependymal flow. Tumor volume was estimated using the products of the largest measurements in 3 anatomic planes divided by 2. Surgical reports were reviewed for intraoperative details, including surgeon assessment of extent of resection. Postoperative imaging and clinical data were evaluated for radiographic extent of tumor resection, ongoing hydrocephalus requiring surgical intervention with ventriculoperitoneal shunting or endoscopic third ventriculostomy, need for subsequent tumor resection, surgical time (if available), length of stay, and discharge destination (home vs inpatient rehabilitation).

Statistical comparison of the iMRI and non-iMRI groups was completed using Fisher tests for binary criteria, the Student *t*-test for continuous variables, and the Fisher exact test for discrete variables using GraphPad Prism v9 (San Diego). This case series has been reported in line with the PROCESS guidelines.[8]

RESULTS

Patient and Tumor Characteristics

Sixty patients older than 2 years with cerebellar pilocytic astrocytoma resections between 2007 and 2012 were identified. Twenty-eight patients underwent surgical resection with utilization of the iMRI. Thirty-two patients underwent surgical resection without iMRI technologies. Patient and tumor characteristics were compared, and no discernable differences were found based on statistical testing for tumor size, distance from the midline, and cystic nature (Table 1). Intratumoral hemorrhage was found in 10 patients, and transependymal flow was noted in 34 patients. Spinal MRIs were obtained for all patients, and metastatic disease was not found in any of the patients.

Three-Month Outcome After Index Surgery

For the 32 patients who underwent index tumor resection without the aid of iMRI, the average length of surgery was 4.4 ± 1.3 hours (data not available for 8 patients). Three patients were taken back to the operating room within 30 days for residual tumor (2 on POD3 and 1 on POD15). There were no surgical complications associated with these 3 additional surgeries. The recommendation to remove the residual tumor was made based on family preference, tumor biology, size of the residual tumor, and the surgeon's preference. Three patients underwent shunt placement. For discharge, 27 patients (84%) were discharged home, whereas the remaining 5 patients (16%) required inpatient rehabilitation. The average length of hospital stay was 7 ± 2.7 days (range 2-14) (Table 2).

In the 28 patients in the iMRI group, the average length of surgery was 6.1 ± 1.5 hours (data not available for 5 patients). This was significantly different comparing with the non-iMRI group as expected (*t*-test P = .0001). Based on the operative reports, 9 patients underwent additional tumor removal when residuals were identified on the first iMRI scan. Figure A shows such an example where the intraoperative scan (Figure B) revealed a small area of residual superior that was hidden behind overhanging tissue. Of the 9 patients who had further resection after the iMRI scan, only 2 underwent a second iMRI scan with no residual, whereas the remaining 7 patients had subsequent tumor-free imaging. One of these 7 patients experienced de novo recurrence because initial imaging was free of tumor and delayed follow-up imaging revealed enhancing tumor remote from the original resection cavity. After the index operation, no iMRI patients underwent another tumor resection in the first 3 months. Two patients underwent shunt placement when weaning of EVDs was not successful. For discharge, 25 patients (89%) were discharged home, whereas the remaining 3 patients (11%) required inpatient rehabilitation. The average length of hospital stay was 7 ± 1.7 days (range 3-12). There were no differences between discharge destination (Fisher exact P = .7122) and length of stay (*t*-test P = 1.0). There did not seem to be any correlation between who in the iMRI group got an early postoperative scan vs who did not, eg, some who were GTR on the iMRI scan still had early postoperative scans, whereas some who had further resection after the iMRI scan did not have early postoperative scans.

There was a significant difference in the utilization of postoperative MRI between the 2 groups. Although all patients in the non-iMRI group received postoperative MRI, only 10 patients in the iMRI did so and none required reintubation. The interpretations of the reading were often difficult because of surgical changes, specifically distinguishing residual vs postoperative changes. Figure C is an intraoperative scan showing the anterior-superior margin of resection to be clean while Figure D is the POD2 scan showing a rim of enhancement that could be mistaken for residual but was actually simply postoperative changes and devitalized tissue. As a result, MRI obtained at 3 months postoperatively was chosen to represent the new disease status

TABLE 2. Clinical and Surgical Outcomes

Surgical outcome	Non-iMRI	iMRI	*P*-Value
Total no. of patients	32 (53%)	28 (47%)	
Case duration (hr, avg ± std)	4.4 ± 1.3	6.1 ± 1.5	.0001
Length of hospital stay (d, avg ± std)	7 ± 2.7	7 ± 1.7	1.0
Discharged home	27 (84)	25 (89)	.71
Reoperations within 30 d	3 (9)	0	.25
Shunt placement	3 (9)	2 (7)	1.0
Residual tumor at 3 mo	6 (19)	4 (14)	.78
Residual tumor size: avg cm^3	1.3	0.9	.69
Second surgery after 30 d	3 (9)	1 (4)	.61
Length of follow-up (mo, avg ± std)	82 ± 33	71 ± 22	.95
Total no. of reoperations	6 (19)	1 (4)	.11

Avg, average; Std; standard deviation. Numbers in parenthesis are percentages within the group.

after the operation. At 3 months after the index surgery, 6 patients in the non-iMRI group and 4 patients in the iMRI were noted to have small residual tumor (*P* = .78, Table 2).

Long-Term Surgical Outcome

Of the 60 patients, the average follow-up length was 78 ± 26 months (range 36-152). There were no differences between follow-up among the 2 groups (82 ± 33 non-iMRI vs 71 ± 22 iMRI, *P* = .95). Patients were followed up by the Neurosurgery and Neuro-Oncology services, which arranged for follow-up imaging. Patients with known residual disease underwent 1.9 MRIs per patient year, compared with 1.5 MRIs per patient year for those without residual disease. During the follow-up period, 3 patients from the non-iMRI group underwent repeat surgery: 2 patients with known residual tumor were noted to have tumor enlargement on serial imaging and pursued surgery at 3 and 7.5 years postoperatively, respectively. The third patient experienced recurrent disease after documented GTR in multiple scans and subsequently underwent a second surgery 4.5 years after their first resection.

A single patient from the iMRI group was noted to have de novo recurrence after an initial GTR; the second surgery was completed 3.5 years after the initial operation. None of the patients in either group required a third operation. Altogether, although the non-iMRI group underwent 6 total reoperations over the follow-up period compared with 1 in the iMRI group, this difference did not reach significance (*P* = .11, Table 2).

DISCUSSION

Cerebellar Pilocytic Astrocytoma

Multiple reports have documented the excellent long-term prognosis with pediatric cerebellar pilocytic astrocytoma, and the best result is achieved after GTR.[5,7,9-12] In these and other reports, reoperation occurs in a small subset of patients when residual tumor growth was documented. However, spontaneous regression of residual tumor had been reported by multiple groups as well.[11,13,14] Not surprisingly, determination of definitive GTR can sometimes be difficult, stemming from equivocal MRI findings such as nonenhancing tumor and the surgeon's intraoperative assessment.[11]

Our short-term and long-term clinical results are in line with the available reports. Most of our patients were discharged home after a short inpatient stay, and 5 of the 60 patients ultimately required permanent cerebrospinal fluid diversion. GTR was achieved in 83% of patients with or without the use of iMRI based on MRI obtained at 3 months postoperatively. Four of the 60 patients required a second resection after the initial 30-day postoperative window: 2 because of the enlargement of the residual tumor and 2 because of de novo recurrence after GTR.

Limitations

It is often difficult to determine the usefulness of a surgical adjunct, whether it is intraoperative angiogram, neuromonitoring, and image guidance, among others. The potential benefits of an added tool have to be balanced against a longer operative time, higher cost, and increased complications. Disease-related and surgeon-related factors often confound the interpretation of such studies. In this study, we attempted to minimize variations in disease-related factors by choosing a singular entity and center. To the best of our knowledge, there has not been a study evaluating the added value of iMRI while controlling both tumor pathology and posterior fossa location. As for surgeon-related factors, all our surgeons agree with the principle of maximally safe resection, but the decision-making process on whether to use iMRI was not documented. As mentioned in the Methods section, the iMRI was only available at 1 of the 2 facilities starting in 2009. After then, all surgeons had the option to use it, but still many cases were performed without it based on the surgeon's preference or physical availability. One of the 5 surgeons did not end up using the iMRI during the study period, but their reasoning was not specifically documented. From the preoperative demographics (Table 1), both groups seem similar. Finally, the decision for reoperation was appropriately tailored to family preferences but under the surgeon's influences. One family had opted for reoperation for a readily accessible sub-1 cm^3 residual lesion, whereas another family elected to monitor a larger volume (3 cm^3) residual tumor. These 2 cases highlight the complexity of the decision to reoperate, and we, therefore, suggest that the absence or presence of residual may be a more definitive outcome to future studies. Furthermore, to look specifically at cost, future studies might compare iMRI runtime cost vs non-iMRI runtime cost plus postoperative MRI cost. In fact, the 1 significant finding of this study was that iMRI had longer OR time as expected.

Studies suggest that the use of iMRI tends to decrease the likelihood of residual on follow-up imaging and thus theoretically reduces the need for immediate reoperations.[2-4,15] Our data showed similar trends but did not reach statistical significance. A larger sample size may reveal a difference.

CONCLUSION

Hemispheric cerebellar pilocytic astrocytomas represent a specific pathology where GTR likely represents a cure. Intraoperative MRI gives valuable feedback and may decrease the need for reoperations; however, this did not achieve statistical significance in our series.

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