LIMITED BENEFIT OF INTRAOPERATIVE LOW-FIELD MAGNETIC RESONANCE IMAGING IN CRANIOPHARYNGIOMA SURGERY

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OBJECTIVE: To investigate the benefit of intraoperative low-field magnetic resonance imaging (MRI) in craniopharyngioma surgery.

METHODS: We used a 0.2-T Magnetom Open scanner (Siemens Medical Solutions, Erlangen, Germany) that was located in a radiofrequency-shielded operating theater for intraoperative MRI. The head of the patient was placed in the fringe field of the scanner, so that standard microinstruments could be used. In transsphenoidal surgery, T1-weighted coronal and sagittal images were acquired. In transcranial surgery, a three-dimensional, gradient echo, T1-weighted, fast low-angle shot sequence was measured, thus allowing multiplanar reformatting.

RESULTS: A total of 21 surgical procedures in craniopharyngioma patients were investigated. In 10 patients, a bifrontal-translaminar approach was used; in 6 patients, the craniopharyngioma was removed via a transsphenoidal approach; and in 5 patients, intraoperative MRI was used to monitor cyst puncture and aspiration. In the craniotomy group, intraoperative imaging depicted a clear tumor remnant in one patient, which was subsequently removed. In another patient, an area of contrast enhancement was interpreted as artifact; however, postoperative follow-up at 3 months was suspicious for a minor remnant. Two of the eight patients with complete removal developed a recurrence during the follow-up period. In the group of patients who underwent primary transsphenoidal surgery (n = 4), complete removal was estimated by the surgeon in three cases. Intraoperative imaging depicted a remaining tumor in one case, leading to further tumor removal; however, follow-up revealed recurrent cysts.

CONCLUSION: Intraoperative low-field MRI allows an ultraearly evaluation of the extent of tumor removal in craniopharyngioma surgery in most cases. Imaging showing an incomplete resection offers the chance for further tumor removal during the same operation. However, intraoperative low-field MRI depicting a complete resection does not exclude craniopharyngioma recurrence.

KEY WORDS: Craniopharyngioma surgery, Intraoperative magnetic resonance imaging, Low-field magnetic resonance imaging

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The surgical management of craniopharyngiomas is still challenging and is often considered controversial (31). Surgical regimens range from conservative, limited surgery combined with radiation therapy to attempts at primary complete resection. Major advancements in the past 2 decades include improvements in hormone replacement therapy, better preoperative imaging supporting the neurosurgeon's choice of the optimal approach, and enhanced microsurgical techniques. Total tumor removal while avoiding hazardous intraoperative manipulations provides favorable early results and a high rate of long-term control (11). In earlier times, the claim of total removal was based on the surgeon's intraoperative impression, which, by itself, is no longer sufficient; today, postoperative imaging is required to define complete removal.

In addition to preoperative and postoperative progress in craniopharyngioma management, new intraoperative techniques, such as endoscopy, neuronavigation, and intraopera-

tive imaging, may offer new benefits for craniopharyngioma treatment (11). Intraoperative imaging may improve the extent of resection, but it can also demonstrate the limitations of surgical resection.

Magnetic resonance imaging (MRI) was introduced into the neurosurgical operating room in 1995 (3); since then, different concepts have been developed, including dedicated low- and high-field MRI scanners for intraoperative use, as well as the adaptation of standard MRI scanners to the operating room environment. One of the main indications for intraoperative MRI is the evaluation of the removal of large pituitary adenomas with a distinct suprasellar extension (5, 10, 21, 30). Because intraoperative MRI has proven to be valuable in pituitary adenoma surgery, there is an obvious need to investigate whether craniopharyngioma surgery would also benefit from it.

Until now, only anecdotal reports have been published on intraoperative MRI in craniopharyngioma surgery (12, 20, 39). The aim of the present study was to give an overview of our experience with intraoperative low-field MRI in craniopharyngioma surgery.

PATIENTS AND METHODS

Patient Population

In a nonconsecutive series of 20 patients (10 female, 10 male; age, 8–50 yr; one patient [Patient 2] was operated on twice) who harbored large suprasellar craniopharyngiomas and in whom we performed 21 surgical procedures, intraoperative MRI was applied either to evaluate the catheter position for the drainage of craniopharyngioma cysts or to evaluate the extent of craniopharyngioma removal in transsphenoidal or transcranial surgery. Patient details are summarized in *Tables 1 through 3*. Before surgery, all patients gave their informed consent for intraoperative MRI.

All patients underwent a sophisticated preoperative and postoperative endocrinological and ophthalmological evaluation, as previously published by our group (11, 13). Endocrine findings were documented as partial pituitary functions (hypogonadism, hypothyroidism, hypocortisolism, and diabetes insipidus).

MRI

Intraoperative MRI was performed using a 0.2-T Magnetom Open scanner (Siemens Medical Solutions, Erlangen, Germany), which is located in a radiofrequency-shielded operating theater. Details of the operating room setup have been published previously (27, 35). Intraoperative images were compared with follow-up controls, which were obtained routinely 3 months after surgery.

Catheter Placement

For frameless stereotaxy, the head was fixed in an MRI-compatible headholder. The catheter was inserted using the

TABLE 1. Craniopharyngioma patients treated with cyst puncture[a]

Patient no.	Age (yr)/ sex	Tumor location	Clinical signs	Intraoperative MRI	Postoperative course	Further treatment
1	9/M	SS and RS	Hypocortisolism, hypogonadism; V, 0.6/ 0.6	Catheter placement confirmed	DI; V, 0.6/0.6	Bifrontal translaminar surgery 3 d later
2	10/M	IS and SS, and left frontal	Seizures, hyposomatotropism; V, 0.6/0.6	Catheter placement confirmed, cyst drainage monitored	V, 0.8/0.8	Bifrontal translaminar surgery 4 mo later
3	8/M	SS and left frontal	6 yr earlier transcallosal surgery, RTX, last STX 24 mo earlier; anterior pituitary insufficiency; V, 0.3/0.08 incomplete bitemporal hemianopsia	Catheter placement confirmed	Unchanged	Repeated cyst drainage via Rickham reservoir
4	28/M	SS, multicystic	V, 0.3/1.0	Catheter placement confirmed	V, 0.5/1.0	Transcranial surgery 1 mo later, panhypopituitarism
5	37/F	IS and SS	8 yr earlier transcranial surgery, panhypopituitarism, last STX 2 mo earlier, RTX; V, 1.0/0.8 upper bitemporal hemianopsia	Catheter placement confirmed	Visual field improved	

[a] MRI, magnetic resonance imaging; IS, intrasellar; SS, suprasellar; RS, retrosellar; STX, stereotactic catheter placement; RTX, radiation therapy; V, visual acuity; DI, diabetes insipidus.

TABLE 2. Craniopharyngioma patients operated on via a transsphenoidal approach[a, b]

Patient no.	Age (yr)/ sex	Tumor configuration/ maximum diameter	Clinical signs	Surgeon's estimation of removal	Intraoperative MRI	Postoperative course	Result of first follow-up MRI after 3 mo	Total follow-up time	Recurrence
6	38/F	IS and SS/15 mm	Superior temporal anopsia right	Complete	Complete, drill artifacts, IS blood	No deficit	Complete	3 mo	No
7	14/M	IS and SS, compression of optic chiasm/19 mm	Mild hyperprolactinemia, loss of vision (V, 1.0/ 0.3), retroorbital pain, headache	Complete	Incomplete; repeated inspection and further removal	Improvement of vision (1.0 both sides)	Recurrent cysts	16 mo	After 3 mo, IS cystic lesion
8	18/M	IS and SS elevated chiasm, cystic/3.5 cm	Pubertas tarda, primary hypogonadism, right temporal hemianopsia; V, 0.3/0.8	Complete	Complete (in T2)	Panhypopituitarism	Complete	3 mo	No
9	13/F	IS and SS chiasm attached, cystic/3 cm	Hypogonadism, hyposomatotropism, bitemporal superior anopsia	Uncertain (small capsule remnants)	Complete	Hypocortisolism, DI, visual field improved	Small IS cyst	33 mo	After 3 mo, small IS cyst
10	45/F	IS and SS/18 mm	12 mo previous transcranial surgery and RTX, headache, panhypopituitarism	Complete	Complete, drill artifacts	CSF leakage, remaining panhypopituitarism	Complete	52 mo	After 31 mo, cystic lesion between stalk and chiasm
11	18/F	IS solid and SS cystic/15 mm	5 yr previous transcranial surgery, panhypopituitarism; V, 1/50/1.2	Complete	Complete	CSF leakage, panhypopituitarism	Complete	19 mo	No

[a] MRI, magnetic resonance imaging; IS, intrasellar; SS, suprasellar; RTX, radiation therapy; V, visual acuity; DI, diabetes insipidus; CSF, cerebrospinal fluid.
[b] Two patients (Patients 10 and 11) had previous transcranial surgery.

guidetube of the neuronavigation system (Stealth, Medtronic, Broomfield, CO). A flexible MRI coil was attached around the head for imaging. After cyst puncture, the patient was transported from the neighboring operating room into the scanner using an air-cushioned operating table (35); then, imaging started. The placement of the catheter was visualized by measuring a T1-weighted, three-dimensional, fast low-angle shot, gradient echo sequence (slice thickness, 1.5 mm; TR, 16.1 ms; TE, 7 ms; bandwidth, 98 Hz; field of view, 250 mm; matrix, 256 $\times$ 256), which allows multiplanar reformatting, so that the course of the catheter could be displayed in a reformatted slice. Furthermore, a T2-weighted turbo spin echo sequence (slice thickness, 3 mm; TR, 5700 ms; TE, 117 ms; bandwidth, 33 Hz; field of view, 230 mm; matrix, 224 $\times$ 256) could be applied. To monitor cyst drainage, an axial T1-weighted spin echo sequence (slice thickness, 3 mm; TR, 340 ms; TE, 26 ms; bandwidth, 39 Hz; field of view, 200 mm; matrix, 192 $\times$ 256) was measured repeatedly.

Transsphenoidal Surgery

The head of the patient was placed directly on the movable table of the MRI scanner at the 5-Gauss line. A standard flexible coil was attached around the head. In addition to a MRI-compatible speculum and porcelain-coated drills, which were used to minimize drill artifacts, standard microinstruments were used. For intraoperative scanning, the table slid into the center of the magnet, and then data acquisition could be started. In the routine setup, coronal and sagittal T1-weighted spin echo sequences (slice thickness, 3 mm; TR, 340 ms; TE, 26 ms; bandwidth, 39 Hz; field of view, 200 mm; matrix, 192 $\times$ 256) were acquired. A T2-weighted turbo spin echo sequence (parameters as above) was sometimes measured.

Transcranial Surgery

All patients were operated on via a bifrontal-translaminar approach by the senior author (RF). In transcranial surgery, the head was fixed in a ceramic, MRI-compatible headholder. In combination with the MKM navigation microscope (Zeiss, Oberkochen, Germany), which was the only available navigation microscope in 1996, surgery was performed in an adjacent operating room (twin operating room concept). The patient lay on an air-cushioned operating room table for transport to the scanner during surgery (transport occurred over a distance of 5 m). With the introduction of the NC4 navigation microscope (Zeiss), which consists of only a few magnetic parts, intraoperative pa-

TABLE 3. Craniopharyngioma patients operated on via a transcranial (bifrontal-translaminar) approach[a]

Patient no.	Age (yr)/sex	Tumor configuration/ maximum diameter	Clinical signs	Surgeon's estimation of removal	Intraoperative MRI	Postoperative course	Result of first follow-up MRI after 3 mo	Total follow-up time	Recurrence
12	47/M	SS, RS and third ventricle and brainstem/2.5 cm	No endocrine deficit, bitemporal hemianopsia, optic nerve atrophy, loss of concentration	Complete	Complete	DI, deficit left lower temporal quadrant; V, 0.5/ 0.6, secondary hypogonadism	Complete removal	42 mo	No
13	37/M	Third ventricle, multiple cysts, solid part/4 cm	Mild hyperprolactinemia, secondary hypogonadism, hyposomatotropism, visual field deficit right temporal; V, 0.3/0.8	Complete	Complete	Panhypopituitarism, improvement visual field; V, 0.8/1.0	Complete removal	41 mo	After 41 mo, IS 0.8 cm, cystic
14	14/F	IS, SS, RS and third ventricle, solid, calcified/4 cm	Primary amenorrhea, growth inhibition, hypogonadism, hyposomatotropism	Complete	Complete	Loss of concentration	Complete removal	30 mo	No
15	32/M	IS, SS and RS, chiasm elevated, hypothalamic compression, cystic/3.5 cm	2 mo earlier STX, hyposomatotropism, bitemporal hemianopsia, memory disturbance	Complete	Complete	Panhypopituitarism, improvement in visual fields, CSF leakage	Complete removal	13 mo	No
16	37/F	IS, SS and third ventricle, attached basilar artery/3.5 cm	STX earlier, mild hyperprolactinemia, hyposomatotropism, bitemporal hemianopsia; V, 0.8/0.16	Complete	SS remnant, further removal	Hypocortisolism, hypogonadism, DI, right temporal hemianopsia; V, 0.7/0.5, organic brain syndrome	Complete removal	19 mo	After 12 mo, 2 cysts IS, reoperated; V, 0.6/0.03, bitemporal
17	50/F	IS, SS and third ventricle, multicystic/ 2.5 cm	Hypothyreosis, hyposomatotropism, narrowing of visual fields; V, 0.8/0.6	Complete	Complete	Insufficiency of anterior pituitary, hypothalamic disorder; V, 1.0/ 1.0, incomplete bitemporal hemianopsia	Complete	21 mo	No
18	50/M	SS and RS, solid and cystic, partially calcified/3 cm	STX earlier, insufficiency of anterior lobe	Complete	Complete	Panhypopituitarism	Complete	3 mo	No
19	48/F	SS and slight RS, compression of optic chiasm/3 cm	Bitemporal hemianopsia	Complete	Complete	Hypogonadism, DI, improvement of visual field	Complete removal	9 mo	No
2	10/M	IS, RS and left frontal/6 cm	STX 3 mo earlier, hyposomatotropism, bitemporal hemianopsia	Complete	Complete	DI, improved bitemporal hemianopsia	Cystic recurrence SS left	4 mo	3 mo
20	19/M	IS and SS, chiasm, elevated/3 cm	STX earlier, headache, visual field deficit	Complete	Complete/uncertain artifact	Hypopituitarism, improvement of visual field	Diffuse contrast enhancement floor third ventricle	4 mo	4 mo

[a] MRI, magnetic resonance imaging; IS, intrasellar; SS, suprasellar; RS, retrosellar; STX, stereotactic catheter placement; V, visual acuity; DI, diabetes insipidus; CSF, cerebrospinal fluid.

tient transport could be abandoned, and all procedures could be performed in the same position as in transsphenoidal surgery (27). A separable coil was used for imaging. The lower, unsterile part of the coil was applied before surgery. The sterile, upper part of the coil was placed onto sterile adapters just before the head was moved into the center of the scanner. Volume data were obtained routinely using a T1-weighted, three-dimensional, fast low-angle shot, gradient echo sequence (parameters as above). This sequence was used for multiplanar reformatting to obtain standard projections. The MRI contrast agent (gadolinium-diethylenetriamine penta-acetic acid, 0.2 ml/kg body weight, administered intravenously) was given just before scanning.

RESULTS

In five patients (*Table 1*; Patients 1–5), intraoperative MRI was used to monitor intracystic catheter placement. In all of these patients, imaging depicted a satisfactory placement. In one patient, repeated intraoperative imaging allowed us to monitor the drainage and irrigation of a giant craniopharyngioma cyst (*Fig. 1*).

In five of the six craniopharyngioma patients (*Table 2*; Patients 6–11) who were operated on by a transsphenoidal approach, intraoperative MRI was interpreted as depicting complete removal (*Fig. 2*). In the group of patients undergoing primary transsphenoidal surgery (n = 4), complete removal was estimated by the surgeon in three cases. In one patient (Patient 7) who had a two-thirds suprasellar tumor extension, intraoperative imaging resulted in further tumor removal, but follow-up examinations showed recurrent craniopharyngioma cysts. In one patient (Patient 9) who had primary transsphenoidal surgery, the surgeon was uncertain whether he had completely removed all cyst walls. Intraoperative imaging did not show any tumor remnants; however, postoperative control scans revealed a recurrent small intrasellar cyst. In one patient (Patient 10) who had been operated on 12 months earlier via the transcranial route, intraoperative imaging and 3-month follow-up imaging depicted complete removal; however, after 31 months, there was a recurrence at the pituitary stalk owing to the primary supradiaphragmatic tumor localization.

In the craniotomy patients (*Table 3*; Patients 2 and 12–20), who were all operated on by means of a bifrontal-translaminar approach, intraoperative imaging depicted complete removal in eight patients (*Figs. 3* and *4*). In one patient (Patient 16), a clear tumor remnant was visible; this was removed consecutively (*Fig. 5*). The postoperative control scan, obtained 3 months later, confirmed complete removal (*Fig. 5D*). However, there was a recurrence after 12 months, which interestingly was not localized at the site where intraoperative imaging had depicted a remnant during surgery (*Fig. 5E*). In another patient (Patient 20), there was an area of contrast enhancement that was interpreted as artifact; however, postoperative follow-up scans at 3 months showed a small tumor remnant. Two of the eight patients with complete removal developed a recurrence in the follow-up period (after 41 and 3 mo).

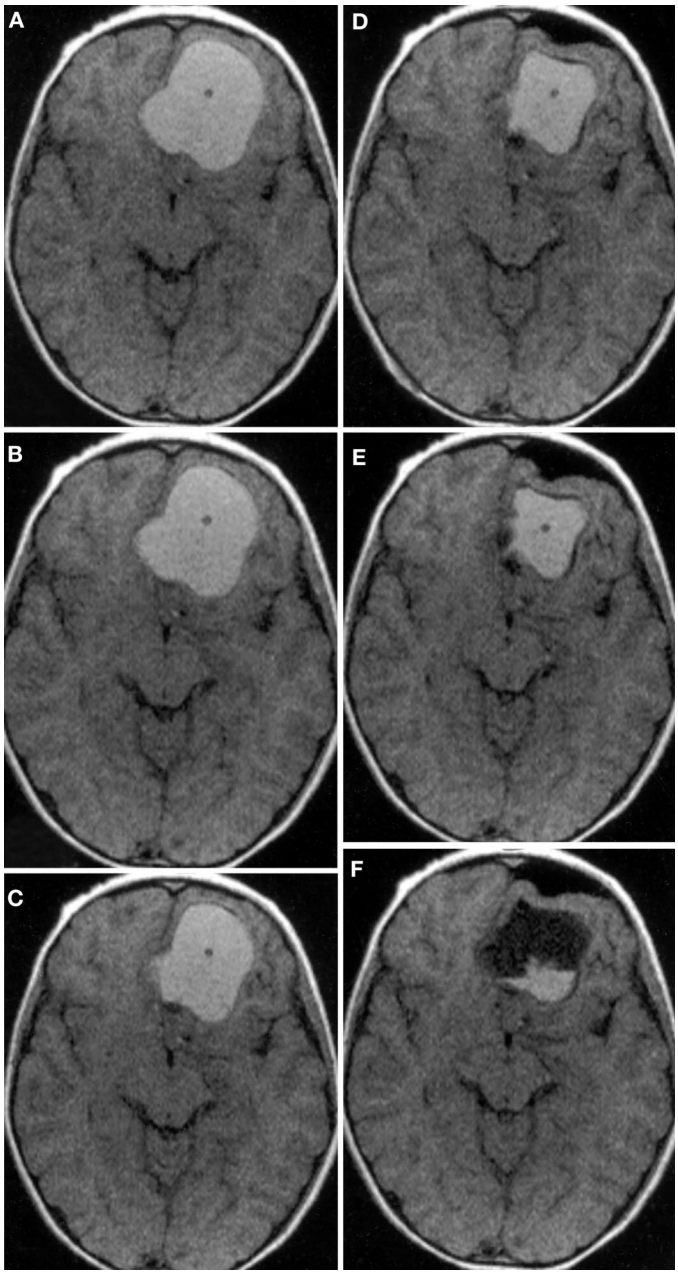

FIGURE 1. *Patient 2, a 10-year-old boy with a very large, mainly cystic craniopharyngioma (intraoperative MRI scans, axial views). After insertion of a catheter into the cyst, the cyst contents were aspirated slowly. At every 10 ml, repeat imaging was performed* (A–E)*. When a significant infolding of the cortex occurred* (E)*, aspiration was stopped, and only further irrigation was performed. Repeat imaging showed the altered cyst contents* (F)*.*

Image quality of the low-field intraoperative images was sufficient to evaluate the effects of surgery in all 21 cases with regard to solid tumor removal and cyst evacuation. In 4 pa-

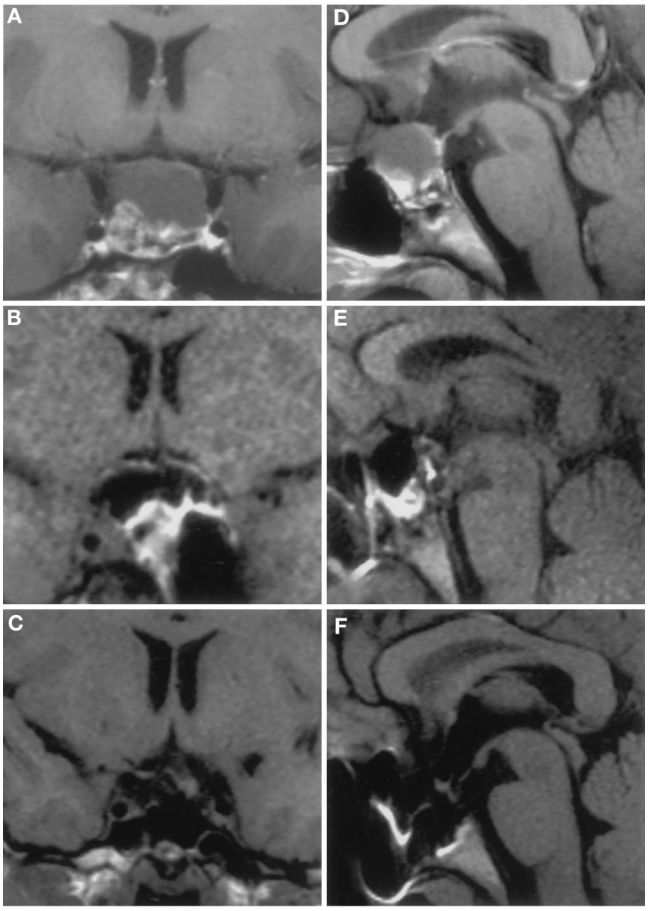

FIGURE 2. *Patient 11, an 18-year-old female patient with a recurrent intrasellar and suprasellar craniopharyngioma. MRI scans (*A–C*, coronal scans;* D–F*, sagittal scans).* A *and* D*, preoperative images.* B *and* E*, intraoperative images depict complete tumor removal, despite some drilling artifacts.* C *and* F*, follow-up scans confirm the intraoperative findings. In* C *and* F*, the drill artifacts are still visible.*

tients (Patients 2, 7, 9, and 20) from the group of 16 patients with either transcranial or transsphenoidal surgery and in whom a total tumor removal was attempted, the postoperative control imaging after 3 months revealed a remaining or recurrent craniopharyngioma, despite the fact that intraoperative imaging was interpreted as complete removal. Retrospectively, the interpretation of the intraoperative finding as artifact in Patient 20 masked a small remnant. In Patient 9, the surgeon was not sure whether he had completely removed the capsule, so the early recurrence is explainable. In Patient 7, the two-thirds suprasellar extension obviously prevented complete removal, despite a second inspection and further removal after intraoperative imaging.

Endocrine and visual outcomes are summarized in *Tables 1 through 3*. We did not encounter additional morbidity caused by intraoperative imaging.

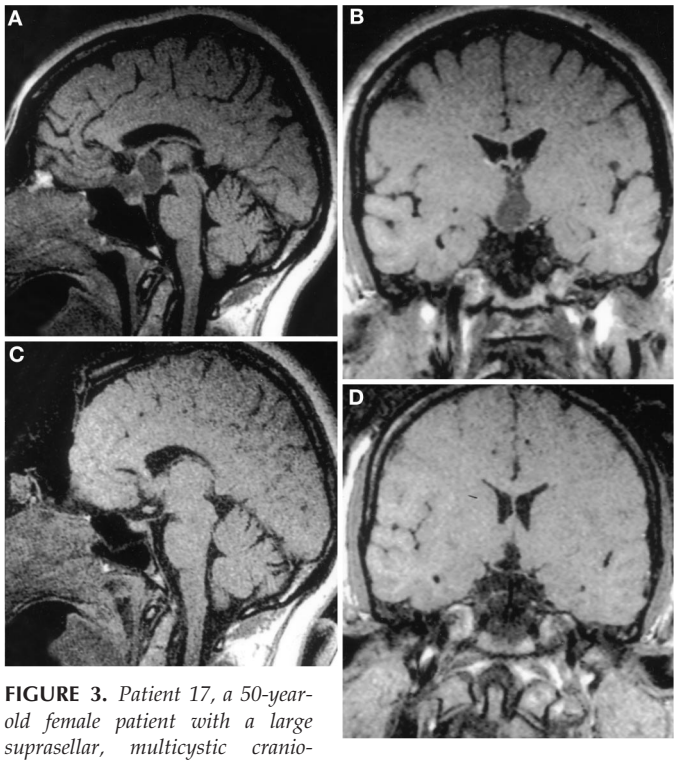

FIGURE 3. *Patient 17, a 50-year-old female patient with a large suprasellar, multicystic craniopharyngioma. MRI scans (*A *and* C*, sagittal views;* B *and* D*, coronal views).* A *and* B*, preoperative scans.* C *and* D*, intraoperative imaging without contrast enhancement, showing complete removal.*

DISCUSSION

The surgical management of craniopharyngiomas has been supported by various advancements in the past few years, such as improved preoperative and postoperative imaging and refined hormonal replacement therapy. Different surgical strategies exist; if there are no severe risk factors, we recommend primary surgery to attempt total removal because, in our experience, total tumor removal while avoiding hazardous intraoperative manipulations provides favorable early results and a high rate of long-term control (11, 13). It is beyond the scope of the present article to discuss the selection of different operative approaches. Recently, new intraoperative techniques, such as endoscopy, neuronavigation, and intraoperative imaging, have also been applied to craniopharyngioma surgery.

Because total removal of craniopharyngiomas seems to be achievable today with low morbidity and mortality rates, total removal must be defined clearly. We doubt that the neurosurgeon's estimation of the extent of tumor removal is more reliable than postoperative imaging (31, 38). Of course, small, microscopic tumor remnants cannot be visualized by the imaging techniques that are available today. However, imaging seems to be the most objective means to evaluate the extent of removal and the only way to monitor the progress of the disease.

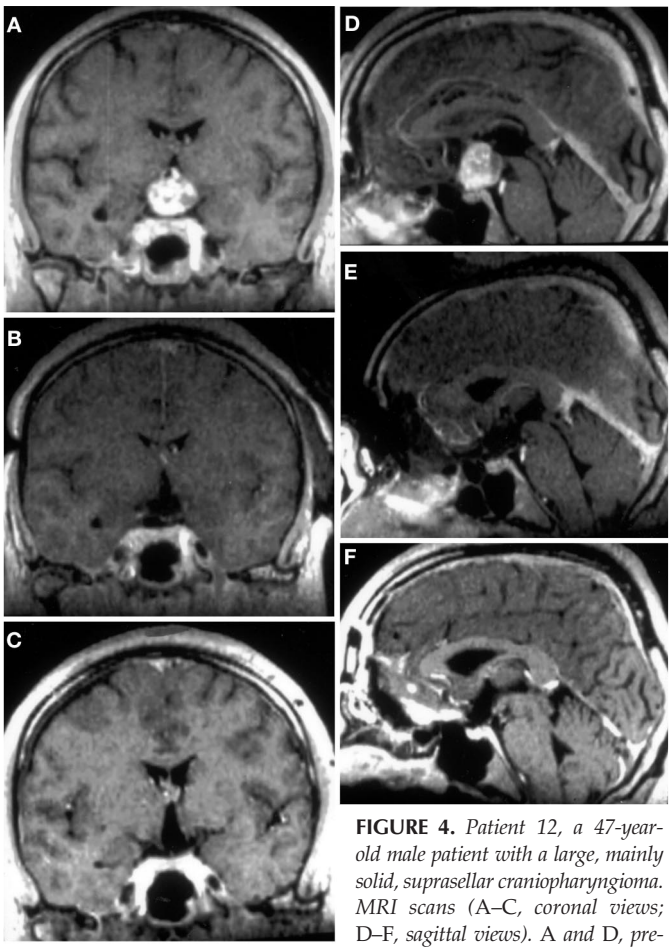

FIGURE 4. *Patient 12, a 47-year-old male patient with a large, mainly solid, suprasellar craniopharyngioma. MRI scans (*A–C*, coronal views; *D–F*, sagittal views).* A *and* D*, preoperative scans. Intraoperative imaging after application of contrast medium depicts complete removal (*B *and* E*), which was confirmed by follow-up imaging after 3 months (*C *and* F*).*

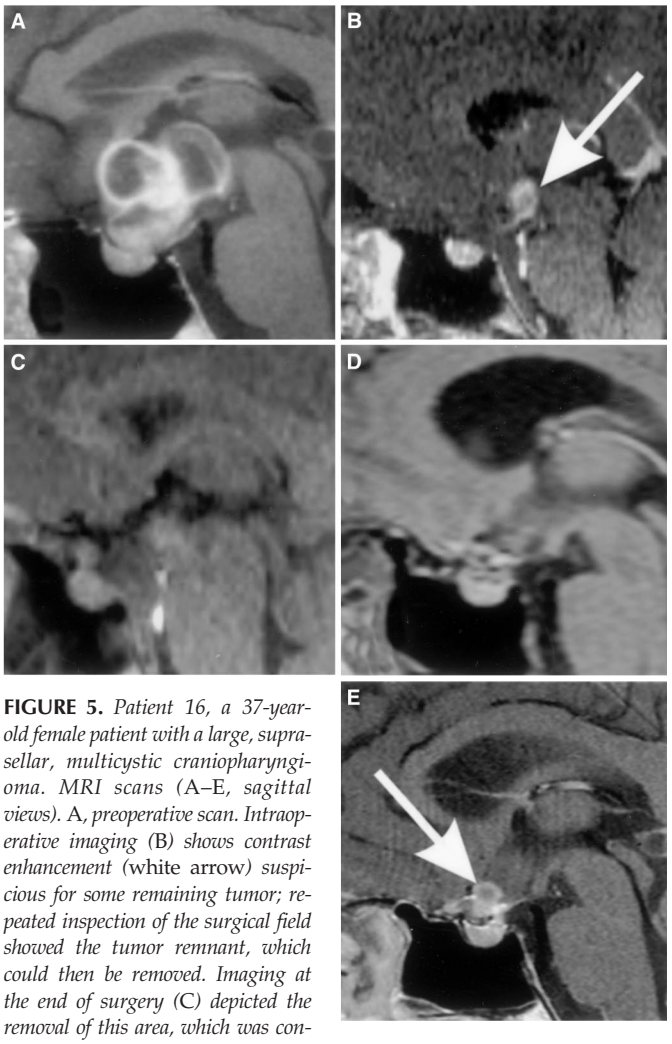

FIGURE 5. *Patient 16, a 37-year-old female patient with a large, suprasellar, multicystic craniopharyngioma. MRI scans (*A–E*, sagittal views).* A*, preoperative scan. Intraoperative imaging (*B*) shows contrast enhancement (*white arrow*) suspicious for some remaining tumor; repeated inspection of the surgical field showed the tumor remnant, which could then be removed. Imaging at the end of surgery (*C*) depicted the removal of this area, which was confirmed by the 3-month follow-up examination (*D*). However, after 12 months, imaging showed a suprasellar recurrence (*white arrow *in* E*), which interestingly was not located at the site of the remnant that had previously been depicted by intraoperative imaging.*

The introduction of intraoperative MRI into the neurosurgical armamentarium in the mid-1990s offered new possibilities for immediate intraoperative quality control (3, 10, 12, 28, 33, 35–37). The different groups investigating intraoperative MRI agree on its valuable use in glioma (2, 4, 6, 19, 23, 32, 41), pituitary adenoma (5, 10, 21), and epilepsy surgery (7, 17, 34) and its ability to compensate for the effects of brain shift when neuronavigation is applied (22, 24, 26, 40). Until now, only anecdotal reports about intraoperative MRI in craniopharyngioma surgery have been published (12, 20, 39). Other imaging modalities, such as ultrasound or computed tomography (CT), have not been investigated extensively for their application in craniopharyngioma surgery; intraoperative CT (29) may have an indication because of its high sensitivity in detecting calcified tumor remnants, which may not be easily detected by intraoperative MRI.

Early postoperative MRI is no alternative to intraoperative imaging, not only because of the lost chance to modify the result of surgery immediately, but also because too many artifacts prevent sufficient image interpretation; only imaging performed after 2 to 3 months provides reliable information about the extent of resection (9, 10).

As demonstrated in our small series, intraoperative MRI is a convenient and reliable technique to monitor craniopharyngioma cyst puncture, to control catheter placement, and to observe cyst aspiration (39). In all patients, intraoperative MRI was technically feasible and added valuable information for the surgeon. We did not observe any morbidity related to imaging; in addition, the overall morbidity in this series was low.

Regarding the value of intraoperative MRI in transsphenoidal and transcranial procedures in which a complete resection was attempted, our nonconsecutive case-control series is surely too small to decide whether intraoperative MRI can increase the extent of craniopharyngioma removal significantly; however, without doubt, it can be stated that when intra-

operative imaging shows an incomplete removal, it enables the neurosurgeon to continue the resection. In 2 of 16 patients in whom we had attempted complete tumor removal, intraoperative imaging depicted a remaining tumor and, thus, resulted in further resection. However, in both complicated cases, the enlarged resection did not prevent a recurrence.

Small remnants of the cyst wall or the microscopic invasion of brain tissue by craniopharyngiomas may be the reason for recurrences, even if intraoperative imaging and the surgeon's estimation have indicated a complete resection. Thus, intraoperative imaging cannot exclude craniopharyngioma recurrences. However, larger tumor portions that may have been overlooked by the surgeon will be clearly delineated and possibly removed during the same operation because of intraoperative imaging. The use of endoscopes enhances the intraoperative viewing abilities of the neurosurgeon (1, 8, 16, 18). We applied endoscopic assistance in all transsphenoidal and transcranial cases; however, in both patients in whom intraoperative MRI depicted a tumor remnant, the endoscopic inspection we performed before intraoperative MRI failed to show the remaining tumor part. The remnants may have evaded detection by endoscopic inspection because of their location in an arachnoidal fold. Furthermore, using the endoscope is a more subjective modality compared with the more objective intraoperative imaging by MRI or CT. It is questionable whether intraoperative CT is more sensitive than intraoperative low-field MRI. However, even modern multislice volume tomographic scanners with their ability to detect very small calcifications will miss microislets of tumor remnants in the same way as low-field MRI.

In 25% of patients in the two groups in whom we attempted complete removal, the first postoperative MRI scan after 3 months depicted a recurrent or remaining craniopharyngioma. In one case, the intraoperative interpretation as artifact masked minor tumor remnants. In another of these four patients, the surgeon was not sure whether he had completely removed the capsule despite the fact that intraoperative imaging depicted complete removal, so the early recurrence can be explained. It seems obvious that tiny capsule remnants cannot be visualized by intraoperative low-field MRI, so they may evade removal. It is an open question whether these cases of "early recurrence," which are probably caused by the tiny capsule remnants, are attributable to the lower image quality of the intraoperative low-field MRI system compared with the high-field MRI systems that are routinely used for the preoperative and postoperative evaluations. We expect that the implementation of an intraoperative high-field MRI scanner with an adapted rotating operating table (25) will further enhance imaging quality, so that there should be no significant difference between preoperative, intraoperative, and postoperative imaging quality. Preliminary results from applying the high-field system in glioma and pituitary adenoma surgery confirm these expectations.

Intraoperative MRI can be seen as only one of a variety of attempts to support and enhance the complex surgical management of craniopharyngiomas; perhaps the application of intraoperative high-field MRI will further increase the significance of the intraoperative evaluation of resection completeness in craniopharyngioma surgery. However, the biological behavior of craniopharyngioma remnants (especially those originating from tiny, undetectable capsule parts) and their hormonal dependency (14, 15) are still a mystery.

CONCLUSION

Intraoperative low-field MRI allows an ultraearly evaluation of the extent of tumor removal in craniopharyngioma surgery in most cases. Imaging that reveals an incomplete resection offers the chance for further tumor removal during the same operation. However, intraoperative low-field MRI depicting a complete resection does not exclude craniopharyngioma recurrence.

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COMMENTS

The subject of image-guided surgery is fascinating to all active neurosurgeons. The intriguing possibility of using intraoperative magnetic resonance imaging (MRI) to control the removal of a variety of intracranial lesions is certainly appealing, but unfortunately a truly user-friendly system that preserves adequate image quality has not yet been developed, and to date no study has demonstrated that imaging guidance improves the outcome for any group of neurosurgical patients.

Having had some limited exposure to the low-field-strength MRI unit described in this article, I must say that although the concept is excellent, the reality is less than perfect, as clearly and carefully documented in this excellent report. In my opinion, there are two problems that have yet to be solved. The first is that the image quality is poor enough that, even with short acquisition time, one is making a significant compromise. The second is that with regard to sellar and suprasellar lesions in particular, my observations have been that after approximately 45 minutes, the operative field tends to fill with blood while the image is being acquired, and that after approximately 45 minutes of operating time, the image density of blood is identical to tissue, making it extremely difficult to resolve whether one is simply dealing with the expected intracapsular hemorrhage or dealing with residual intracapsular tumor, at least in the situation of the typical pituitary macroadenoma with suprasellar extension. These distinctions become even more difficult when one is operating on a lesion as complex as a craniopharyngioma. I am optimistic about the ultimate progress of this technology, and I think that eventually a practical system of intraoperative real-time MRI will provide excellent images in a short period and allow superb control over the removal of a variety of intracranial lesions. Until then, however, the skill and experience of the surgeon is not likely to be replaced by the currently available intraoperative MRI-guided techniques.

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In this article, Nimsky et al. address the role of intraoperative MRI in craniopharyngioma surgery. For a tumor such as craniopharyngioma, in which recurrences frequently occur as a result of residual left at the time of surgery, the application of intraoperative MRI seems promising. Regardless of which route is selected for removal of a craniopharyngioma, a number of blind corridors remain in which small tumor deposits can be left behind. Theoretically, such blind corridors could be assessed and visualized with the use of intraoperative MRI.

The authors show that incomplete resection can be followed by further tumor removal during the same operation. The results also show, however, that complete resection as predicted by MRI does not necessarily exclude craniopharyngioma recurrence. This is no doubt related to microscopic disease, some of which may be calcified and not easily detected by MRI. The other factor, of course, is the limitations of the technology and the low-strength magnet with regard to detecting significant tumor residual.

This group of authors has tremendous experience in the field of craniopharyngioma surgery. Their approach to this exacting tumor with the use of intraoperative MRI was a worthwhile exercise that led to good results.

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The article by Nimsky et al. describes the use of intraoperative low-field MRI in a heterogeneous group of patients harboring craniopharyngiomas treated in different ways (i.e., cyst aspiration, transcranial and transsphenoidal resection). Intraoperative MRI allows further resection in cases in which remnants are visible. Even in several cases in which MRI suggested complete resection, however, tumor recurrence was observed, indicating a false-negative interpretation of MRI scans. It is doubtful whether craniopharyngiomas are an indication for intraoperative MRI at all and low-field MRI in particular. Often microislets of tumors or capsule remnants are not visible during surgery and escape detection with the use of imaging techniques as well. In other cases, further resection would be too dangerous, such as in cases involving hypothalamic infiltration or attachments to the intracranial vessels. Therefore, in my opinion, even the term "limited use" is too optimistic. Certainly, intraoperative MRI can detect optical decompression in transsphenoidal surgery, but this can be accomplished by other means. The use of an endoscope might be even more helpful. This article describes only a feasibility study to demonstrate the use of intraoperative MRI in craniopharyngioma surgery, which seems to me to be technical overkill in treating patients with this tumor entity. Follow-up of 3 months is certainly much too short. The patient benefit regarding increased survival or progression-free interval has not been shown in this study, nor has decreased morbidity been demonstrated with the use of low-field MRI. As the authors correctly point out, it would be interesting to study whether the use of intraoperative high-field MRI enhances the detection of tumor remnants, considering that the 3-month follow-up examinations were performed with a high-field scanner and no immediate postoperative high-field MRI was performed.

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