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Intracystic interferon-alpha in pediatric craniopharyngioma patients: an international multicenter assessment on behalf of SIOPE and ISPN


Abstract

**Background:** Craniopharyngiomas are frequent hypothalamo-pituitary tumors in children, presenting predominantly as cystic lesions. Morbidity from conventional treatment has focused attention on intracystic drug delivery, hypothesized to cause fewer clinical consequences. However, the efficacy of intracystic therapy remains unclear. We report the retrospective experiences of several global centers using intracystic interferon-alpha.

**Methods:** European Société Internationale d’Oncologie Pédiatrique and International Society for Pediatric Neurosurgery centers were contacted to submit a datasheet capturing pediatric patients with cystic
Craniopharyngiomas who had received intracystic interferon-alpha. Patient demographics, administration schedules, adverse events, and outcomes were obtained. Progression was clinical or radiological (cyst reaccumulation, novel cysts, or solid growth).

**Results:** Fifty-six children (median age, 6.3 y) from 21 international centers were identified. Median follow-up from diagnosis was 5.1 years (0.3–17.7 y). Lesions were cystic (n = 22; 39%) or cystic/solid (n = 34; 61%). Previous progression was treated in 43 (77%) patients before interferon use. In such cases, further progression was delayed by intracystic interferon compared with the preceding therapy for cystic lesions (P = 0.0005). Few significant attributable side effects were reported. Progression post interferon occurred in 42 patients (median 14 mo; 0–8 y), while the estimated median time to definitive therapy post interferon was 5.8 (1.8–9.7) years.

**Conclusions:** Intracystic interferon-alpha can delay disease progression and potentially offer a protracted time to definitive surgery or radiotherapy in pediatric cystic craniopharyngioma, yet demonstrates a favorable toxicity profile compared with other therapeutic modalities—important factors for this developing age group. A prospective, randomized international clinical trial assessment is warranted.

**Key words**
craniopharyngioma | intracystic interferon | pediatric | retrospective

**Importance of the study**

Despite advances in neurosurgery and radiotherapy, the management of childhood craniopharyngioma remains challenging because of ongoing posttreatment morbidity concerns. As such, scope remains for therapeutic innovation. The cystic composition of pediatric craniopharyngiomas makes them ideal candidates to evaluate one such development: the instillation of intracystic agents—designed to obtain durable cyst shrinkage with minimum consequent toxicity. This global, multicenter assessment represents the broadest clinical experience ever reported of one such intracystic agent: interferon-alpha. The study is the first to show a progression-free survival advantage for interferon-alpha in cystic craniopharyngiomas compared with established treatments and a delay to definitive surgery or radiotherapy for several years. Interferon-alpha also appears to have an improved toxicity profile compared with historical intracystic therapies, including bleomycin and radioisotopes. Consequently, the authors propose that this study provides foundation for a global, prospective randomized clinical trial of intracystic interferon in childhood craniopharyngioma, now under consideration.

Craniopharyngiomas represent one of the most frequently diagnosed hypothalamo-pituitary lesions in children.{}

Postulated to arise from embryonic remnants of Rathke’s pouch during development of the fetal adenohypophysis, craniopharyngiomas can consist of either cyst cavities lined by secretory squamous epithelium and/or solid components containing both keratin products and calcium.{}

In childhood, craniopharyngiomas are predominantly cystic in composition.{}

Despite a benign histological classification, the most favorable management strategy for pediatric craniopharyngiomas continues to prove controversial as lesional immaturity with several critical structures in the developing brain can pose a significant risk to neurological, visual, endocrinological, and metabolic functioning.{}

Surgical resection is generally considered curative but is often associated with significant morbidity and mortality, while recurrence post complete resection has also been reported.{}

Conformal radiotherapy is the standard adjuvant therapy used, but concerns regarding its use persist regarding neurocognitive, vascular, and endocrinological sequelae, while the efficacy of systemic chemotherapy has proved disappointing.{}

Molecular profiling of these lesions suggests a role for novel targeted biological agents in the future, yet such personalized therapy remains elusive.

Nevertheless, the recent management of pediatric cystic craniopharyngioma has shifted to focus on intralesional therapies, administered via an indwelling catheter with the objective of postponing or sparing the adverse effects of more conventional therapies with minimal clinical consequences for the patient. One such agent that is becoming increasingly favored via this route is interferon-alpha, on the premise that craniopharyngioma cyst walls share their cells of origin with squamous cell skin carcinomas, where interferon is a recognized antiproliferative and immunomodulatory therapy.{}

Institutional reports of intracystic interferon in craniopharyngioma appear promising, suggesting an acceptable side-effect profile and effectiveness at inducing tumor response.{}

However, conclusions on the efficacy of this therapy remain cautious, since analyzed cohorts were limited in size and the duration of any responses observed remain unpublished.
In an attempt to address this, we have performed an international, multicenter retrospective analysis of intracystic interferon use in pediatric craniopharyngioma among participating institutions within SIOPE (the European subgroup of the International Society of Pediatric Oncology) and ISPN (the International Society of Pediatric Neurosurgery). The efficacy of intracystic interferon in delaying or preventing both disease progression and the need for subsequent definitive surgery or radiotherapy were evaluated, along with toxicity and clinical outcomes following treatment.

**Methods**

Clinical leads for pediatric oncology and neurosurgery from member institutions of both SIOPE and ISPN were invited electronically to complete an anonymized datasheet for any patients aged below 18 years with a histologically proven or radiologically suspected craniopharyngioma that had received intracystic interferon-alpha therapy at any time point in that center. Patients with solid craniopharyngiomas, incompatible histological diagnoses, or age older than 18 years were excluded. Data were collected on patient demographics, presenting symptomatology, timings of all therapies, adherence to the Toronto protocol for intracystic interferon administration\(^9\) (Fig. 1), intracystic dose scheduling, acute and long-term adverse effects of interferon therapy, and clinical outcomes. Toxicity of drug administration was graded as per the National Cancer Institute’s Common Terminology Criteria for Adverse Events (CTCAE). The study received approval from the local research ethics boards of responding centers.

Lesional size was measured radiologically, irrespective of composition, according to the 2 largest diameters from axial, sagittal, and coronal MR images using fluid attenuation inversion recovery sequences and T1-weighted images (with and without contrast enhancement). A largest diameter threshold of 4 cm, in keeping with published literature,\(^26\) was used to delineate large and small lesions for survival analysis comparisons as defined below.

Statistical analyses were performed using SPSS v22.0. Symptom interval was defined as the time elapsed from initial complaint to diagnostic scan. Comparison of parametric continuous variables was performed by independent sample \(t\)-testing with 95% confidence intervals. Survival analysis was performed by the Kaplan–Meier method with significance values for comparisons established by the log rank test. Progression-free survival (PFS) was defined in years from the date of tumor diagnosis to the date of further disease progression (clinical or radiological), death, or censoring if alive. Radiological progression encompassed cyst reaccumulation, novel cyst formation, or solid growth from the date of last intervention. Definitive therapy was defined as either surgical tumor resection or focal radiotherapy. Median follow-up was estimated by the inverse Kaplan–Meier method.\(^27\) Significance was achieved with \(P\)-values below 0.05.

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**Fig. 1** CNS permeability studies revealing contrasting craniopharyngioma cyst wall integrity and the Toronto protocol for intracystic interferon-alpha administration. CNS permeability studies—a sagittal CT (A) and axial CT (B) of the brain post instillation of contrast through an Ommaya reservoir ruling out leakage. This is clearly distinct from a sagittal CT (C) and a coronal CT (D) of the brain post contrast instillation through an Ommaya reservoir demonstrating leakage of contrast through the cyst wall into the body of the right lateral ventricle and adjacent foramen of Monro. These images are alongside the administration schedule for intracystic interferon-alpha devised by the Hospital for Sick Children, Toronto. This is generally accepted as the global standard of care protocol.

<table>
<thead>
<tr>
<th>Intracystic Interferon Administration Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug</td>
</tr>
<tr>
<td>Interferon-alpha-2b</td>
</tr>
</tbody>
</table>

- Cycle may be repeated depending on response.
- Before initiation of treatment a permeability study should have ruled out leakage of contrast and confirmed appropriate position of the tip of the ommaya catheter within the cyst. This permeability study is recommended to be performed 2 weeks after catheter placement or later.
- At the start of therapy (day 1) the maximum possible amount of cystic fluid should be removed before injection of interferon alpha, taking the result of the permeability study (cyst volume) and patient comfort into account. A Normal Saline flush (1 mL) should follow interferon alpha injection.
- For subsequent administrations in the cycle, cystic fluid aspirations for at least 1.5–2 mL should be performed, followed by 1 mL (3 million IU) interferon-alpha injection, followed by 1 mL flush of normal saline.
Results

Demographics

Fifty-six patients from 21 responding SIOPE and ISPN centers fulfilled the inclusion criteria (Table 1, Supplementary Table S1). The median age of the cohort was 6.3 years (range 0.3–17 y) with a male:female ratio of 1.2:1. A histological diagnosis of adamantinomatous craniopharyngioma was made from lesional tissue for 37/56 (66%) patients. This was following an initial biopsy (n = 15) or definitive surgical resection (n = 22), either at diagnosis (n = 20) or following eventual surgical intervention (n = 2). In the 19 other remaining cases, diagnosis was radiological (based on tumor location, presence of calcification on CT imaging, etc) in combination with the presence of classical craniopharyngioma cyst fluid (documented intraoperatively as thick and oil-like and/or with the presence of cholesterol crystals on histology). Of the 20 children who underwent upfront definitive surgery, macroscopic tumor resection was achieved in 3 cases, while an incomplete resection or debulking was recorded for 17 cases. Almost 40% of the group (n = 22) appeared either purely or predominantly cystic on imaging, while two-thirds of children had radiological evidence of hypothalamic involvement.

With respect to the timing of treatment initiation from diagnosis, 48 (86%) patients were treated either immediately or within days of diagnosis. For the remaining 8 children, therapy was initiated at a median of 2 months (range 1–6 mo) from diagnosis. Intracystic interferon therapy was the initial treatment for 13/56 (23%), with the remaining cohort having undergone preceding therapies, including cyst aspiration/fenestration, tumor excision, focal radiotherapy, and radioisotope therapy (Supplementary Table S2). Across the entire cohort, 29 (52%) patients underwent cyst aspiration or fenestration as part of prior therapy. This was performed as either a one-time procedure for 17 (59%) patients or multiple times for 12 (41%) children. Seventeen (30%) patients had been previously treated with radiotherapy, including conformal radiotherapy (n = 9), gamma knife radiosurgery (n = 5), and proton beam therapy (n = 3) (Supplementary Table S3). The median dose administered was 54 Gy (21.8–54 Gy), while the median time to progression following this treatment modality was 2 years (0.3–9 y). Of the 22 patients with predominantly cystic lesions, interferon was the primary therapy in 6 cases (27%), while preceding therapies included aspiration alone (n = 10; 45%), fenestration (n = 3; 14%), surgical resection (n = 2; 9%), and radiotherapy (n = 2; 9%).

Clinical Presentation

Across the cohort, the most common presenting features at diagnosis included raised intracranial pressure (37/56, 66%), pituitary endocrinopathies (25/56, 45%), impaired visual acuity (25/56, 45%), visual field cuts (18/56, 32%), behavioral difficulties (8/56, 14%), and cognitive decline (3/56, 5%). The median symptom interval was 3 months (0.3–48 mo).

Unsurprisingly, at the point of commencing intracystic interferon therapy, a higher proportion of patients had developed clinical anomalies compared with presentation. Raised intracranial pressure had been observed in 40/56 children (71%), while reduced visual acuity was recorded for 30/56 (54%), pituitary dysfunction in 27/56 (48%), visual field deficits in 20/56 (36%), behavioral problems in 10/56 (18%), and cognitive difficulties in 4/56 cases (7%).

Intracystic Interferon Therapy

Concordance with the Toronto protocol for intracystic interferon administration was generally observed, albeit not universally. Prior to commencing therapy, contrast-enhanced brain imaging to ensure cyst wall integrity was performed in 52/56 (93%) patients. Initial aspiration of the cyst was in accordance with the protocol for 46/56 (82%) children, while each intracystic interferon-alpha dose administered corresponded to 3 million international units across all centers. The median number of doses administered to a patient was 14 (range 6–84) due to several centers offering patients repeated cycles of therapy. However,
7 centers (13%) administered fewer than the standard 12 doses, constituting a typical cycle without an explanatory cause such as secondary toxicity or disease progression.

**Treatment and Outcomes**

At the point of last assessment (median follow-up 5.1 y [range 0.3–17.7 y]; median follow-up post interferon 2.7 y [0.1–10.2 y]), 51/56 (91%) patients remained alive, with 14 (25%) children demonstrating no evidence of disease progression. Five patients died within the follow-up period. Two patients died of ongoing disease progression, 1 died from an endocrinopathy-induced electrolyte imbalance, and 2 died from unrelated, unanticipated infections. All patients had received interferon as the last therapeutic option after repeated surgeries and focal radiation had failed.

In order to assess the comparative impact of intracystic interferon at delaying disease progression in craniopharyngioma, patients who had also received previous therapy were assessed (n = 43). One patient had incomplete PFS data, resulting in an evaluable cohort of 42 children. Across this group, interferon therapy appeared to delay disease progression compared with each child’s corresponding previous treatment (estimated median time to progression = 0.8 y [95% CI: 0.3–1.3 y] vs 0.4 y [95% CI: 0.2–0.6 y], P = 0.022). When this cohort was categorized according to lesional composition, this delay in progression demonstrated that post interferon therapy was exclusively for children with predominantly cystic craniopharyngiomas (estimated median time to progression = 1.3 y [95% CI: 0.7–1.9 y] vs 0.3 y [95% CI: 0.2–0.39 y], P = 0.0005; Fig. 2A), and not for those with solid/cystic lesions (estimated median time to progression = 0.8 y [95% CI: 0.1–1.5 y] vs 0.6 y [95% CI: 0.1–1.1 y], P = 0.339; Fig. 2B). The predominantly cystic cohort trended toward a younger patient age than their solid/cystic counterparts (mean age 5.7 ± 1.1 y vs 7.9 ± 0.8 y, P = 0.1).

Disease progression (radiological or clinical) following intracystic interferon therapy was reported in 42/56 (75%) patients at a median time of 14 months (range 0–8 y; Table 2; Supplementary Figure S1). Neither large lesional size, radiological evidence of hypothalamic infiltration, nor clinical hydrocephalus at presentation impacted significantly on time to progression following interferon administration. Radiological progression due to the development of new cysts or solid tumor growth was observed more frequently than the reaccumulation of previously treated cysts. At the time of last assessment, 14/42 (33%) patients had not undergone definitive surgery or radiotherapy for their progressive disease, instead receiving further courses of intracystic interferon therapy or embarking on periods of clinical surveillance. Of the 24/42 (57%) children who had undergone radical surgery or radiotherapy for disease progression, the median time to such treatment was 5.8 years (1.8–9.7 y). It was not possible to assess the impact of intracystic interferon, before and after use, on time to definitive therapy due to the insufficient numbers of appropriate patients.

**Tolerability and Adverse Events**

The administration of intracystic interferon was generally well tolerated across the cohort, with 23/56 (41%) children...
experiencing no adverse effects during or following therapy. The most common adverse effects included influenza-like malaise (n = 16; 29%), headaches (n = 10; 18%), fatigue (n = 7; 13%), transient hyponatremia (n = 1; 2%), appetite loss (n = 1; 2%), and weight loss (n = 1; 2%). These symptoms were typically grades 1–2 in severity and resolved within days or a short number of weeks without long-standing sequelae.

No toxic deaths attributable to the drug were reported. Nevertheless, 2 cases of suspected significant adverse events were observed. The first case involved a 15-year-old male, previously managed using cyst fenestration and ventriculo-peritoneal shunt insertion for a cystic craniopharyngioma causing raised intracranial pressure, who was treated with intracystic interferon therapy for cystic reaccumulation. After a standard cycle of 12 doses of interferon treatment, the patient developed worsening headaches cumulation. After a standard cycle of 12 doses of interferon therapy, the patient suffered extreme fatigue, while 2 weeks following completion of a standard treatment cycle, he developed extreme confusion, incontinence, and hypernatremia. Imaging at this time revealed worsening hydrocephalus and widespread diffuse brain atrophy, albeit with a stable suprasellar mass. The patient improved neurologically following cerebrospinal fluid (CSF) diversion therapy, but diffuse atrophy persisted on subsequent imaging such that further courses of interferon therapy were abandoned.

### Table 2 Progression and treatment data for craniopharyngioma patients who progressed post intracystic interferon-alpha therapy

<table>
<thead>
<tr>
<th>Patients Progressed after IFN</th>
<th>N = 42</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial radiological appearance</strong></td>
<td></td>
</tr>
<tr>
<td>Cystic</td>
<td>18 (43%)</td>
</tr>
<tr>
<td>Solid/cystic</td>
<td>24 (57%)</td>
</tr>
<tr>
<td><strong>Therapy prior to IFN</strong></td>
<td></td>
</tr>
<tr>
<td>Nil (IFN first therapy)</td>
<td>11 (26%)</td>
</tr>
<tr>
<td>Aspiration/cyst fenestration only</td>
<td>15 (36%)</td>
</tr>
<tr>
<td>Resection + RT</td>
<td>7 (16%)</td>
</tr>
<tr>
<td>Aspiration/cyst fenestration + RT</td>
<td>3 (7%)</td>
</tr>
<tr>
<td>Resection only</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Resection + aspiration</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Resection + RT + aspiration</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Radioisotope + RT + aspiration</td>
<td>1 (2%)</td>
</tr>
<tr>
<td><strong>Type of progression</strong></td>
<td></td>
</tr>
<tr>
<td>Cyst reaccumulation</td>
<td>10 (24%)</td>
</tr>
<tr>
<td>New cyst(s)</td>
<td>12 (29%)</td>
</tr>
<tr>
<td>Solid growth</td>
<td>7 (16%)</td>
</tr>
<tr>
<td>Clinical progression</td>
<td>3 (7%)</td>
</tr>
<tr>
<td>Combination (new cyst[s]/solid/clinical)</td>
<td>10 (24%)</td>
</tr>
<tr>
<td><strong>Subsequent therapy</strong></td>
<td></td>
</tr>
<tr>
<td>Surgery</td>
<td>11 (26%)</td>
</tr>
<tr>
<td>IFN rechallenge</td>
<td>6 (14%)</td>
</tr>
<tr>
<td>Surgery + RT</td>
<td>5 (12%)</td>
</tr>
<tr>
<td>RT</td>
<td>5 (12%)</td>
</tr>
<tr>
<td>IFN rechallenge then surgery</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>IFN rechallenge then surgery +RT</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>IFN to new cysts</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Observation/no intervention</td>
<td>6 (14%)</td>
</tr>
<tr>
<td>Not documented</td>
<td>4 (10%)</td>
</tr>
</tbody>
</table>

**Abbreviations:** IFN = intracystic interferon-alpha; RT = radiotherapy.

### Posttreatment Clinical Outcomes

The effect of intracystic interferon therapy on the most common clinical deficits identified prior to commencing treatment was monitored across the cohort (Fig. 3). Of the 43 patients who had undergone preceding therapy, 25 (58%) developed new clinical deficits between this preceding therapy and the commencement of interferon therapy. Clinical evaluations performed at interferon treatment completion revealed that the vast majority of patients previously suffering from raised intracranial pressure (39/40; 98%), visual acuity decline (27/30; 90%), visual field cuts (18/20; 90%), pituitary dysfunction (26/27; 96%), behavioral difficulties (10/10; 100%), or cognitive deterioration (3/4; 75%) had either stabilized or improved following intracystic interferon therapy alone, thereby suggesting that this treatment could potentially delay or occasionally reverse clinical deterioration in almost all of the patients who receive it.

### Discussion

This global, retrospective analysis of intracystic interferon-alpha therapy in pediatric craniopharyngioma is the first to show a PFS advantage for interferon in children with cystic lesions compared with other established treatments. The study also demonstrates that intracystic interferon therapy may have the potential to delay definitive treatments such as radical surgery or intracranial radiotherapy by several years—a critical benefit for the developing brain, which has a well-established vulnerability to the acute and long-term deleterious effects of such conventional treatment modalities.10,12,14,17,18 Finally, analyzing a cohort with one of the longer follow-up periods to date, we have demonstrated that intracystic interferon appears to stabilize or occasionally reverse clinical deterioration in treated patients with a toxicity profile that is favorable compared with alternative intracystic therapies.9
Interferon-alpha belongs to the interferon cell signaling family of proteins that are produced following pathogenic induction from agents including bacteria, viruses, and neoplasms. While their precise mechanism of action in tumor cells remains elusive, interferons are postulated to be implicated in the generation of an immunological response via immune cell activation, cytokine induction, and inhibition of neoplastic vascularization. Alternatively, interferons may cause direct promotion of cellular differentiation and inhibition of proliferation by modulating signaling mechanisms, including the pathways of phosphatidylinositol-3 kinase and Janus kinase/signal transducers and activators of transcription. Based on these hypotheses, interferon therapy has been used for a range of hematological and solid cancers. The largest of these was a prospective study of 60 children treated across 3 international centers in the period 2000–2009. Thirty-nine patients (65%) received intracystic interferon-alpha as primary treatment, while the remaining children had already undergone either unsuccessful surgery or intracystic bleomycin therapy. The majority of patients (78%) attained more than 50% cyst shrinkage with therapy. While data on disease progression was limited, 13 children (22%) had progressed at a mean follow-up period of 3.7 years and underwent subsequent surgical intervention. Similar to our study, the most frequent side effects observed were mild and transient, and included headaches, palpebral edema, fatigue, and arthralgia. None of these sequelae required discontinuation of therapy and no mortalities were reported. One patient suffered visual decline despite cyst shrinkage, while 8 children developed new endocrinopathies. This study demonstrated that intracystic interferon therapy has a therapeutic benefit in purely or predominantly cystic craniopharyngiomas, yet failed to delay disease progression in lesions comprising a significant solid component. This reflects the observations of groups using this and other intracystic therapies and implies the ongoing need for novel therapies for such solid craniopharyngiomas. In addition, while certain centers advocated retreatment of progressive disease with several cycles of interferon, particularly in the face of cystic reaccumulation, this was not a universal practice, suggesting that...
awareness regarding the ability to repeatedly administer interferon for cystic recurrence is lacking.

Due to limited numbers of appropriate cases, the current study was unable to clearly establish whether intracystic interferon therapy delayed only cystic reaccumulation, as opposed to the development of new cysts or the evolution of solid tissue growth. This may explain why only 2/12 children with new cyst progressive disease underwent reservoir reimplantation and subsequent interferon therapy to these new cysts. Future sizable, clinical trials will help to evaluate this. However, given current knowledge of intracystic interferon toxicity compared with conventional alternatives, such a strategy for new cyst progression seems warranted if feasible. Randomized prospective clinical trials should also help define criteria to define tumor response and address other logistical limitations of this study, including its retrospective nature, the lack of central histological review at diagnosis and central radiological review of initial and follow-up imaging, together with the inconsistent adherence of centers to standardized treatment protocols. Such a study would also allow for a sustained, protracted period of follow-up to assess true impact on visual, endocrine, and cognitive functioning. It is hoped that such future trial work would also contribute samples to ongoing research in craniopharyngioma origin and development, including a focus on pro-inflammatory markers found within cyst fluid, their value as surrogate markers of disease activity, and the subsequent influence on these markers by interferon therapy. In turn, this may further elucidate our understanding of interferon efficacy and tumor response.

Unlike intracystic administration of bleomycin or radioisotopes, the toxicity profile of intrallesional interferon-alpha generated from this analysis is comparatively favorable, with almost half of treated children experiencing no side effects, and the majority of side effects being transient and low grade in severity. Furthermore, no toxic deaths were reported. This echoes the general findings from the other craniopharyngioma studies of intracystic interferon-alpha. Higher-grade toxicity was observed in 2 patients from the current cohort. In both cases, the likely cause was drug leakage into surrounding CSF spaces. In one case, the pretreatment cyst wall permeability study had identified a rupture, but treatment was continued because of interferon's apparent safety profile from literature on its intrathecal administration. The second patient deteriorated with ongoing therapy after initial imaging had revealed an intact cyst wall. However, the initial and cumulative cyst volumes aspirated from this patient are unclear, and the child developed worsening severe headache after several doses had been administered, a clinical sign suggestive of either drug leakage or cyst wall hemorrhage which can occur with vigorous cyst drainage.

Although not observed in the larger cohort analyses, similar case reports of significant toxicity following intracystic interferon-alpha administration in craniopharyngioma are now emerging, secondary to drug extravasation into CSF spaces. In one report, a craniopharyngioma patient suffered a focal neurological event, with subsequent permeability imaging revealing suspected cyst rupture, while another described a 13-year-old patient with recurrent, cystic craniopharyngioma who developed permanent visual field loss and reversible acuity decline following the concomitant administration of intracystic and subcutaneous pegylated interferon-alpha. Retrospective permeability imaging revealed a cyst wall leak. Such results reinforce the importance of performing a permeability imaging study before and, if required, during intracystic therapy and acting on the results obtained. Despite interferon being used as a safe intrathecal agent in other contexts, its evaluation as an intratumoral agent in craniopharyngioma remains a work in progress. In this regard, when radiological evidence of cyst wall permeability is encountered, it is the authors’ recommendation that ongoing treatment with interferon should not proceed. This stance should remain until several outstanding aspects of intracystic interferon use are elucidated from further clinical trial work in craniopharyngioma, such as the most suitable drug formulation and schedule, whether previous therapy influences the likelihood of treatment failure or success, and whether lesional or patient subgroups gain benefit compared with others. Until then, decisions regarding suitable candidates for intracystic interferon therapy should remain within the confines of a craniopharyngioma multidisciplinary team setting, with a stipulation that all proposed patients undergo cyst wall permeability screening as required with treatment suspension if extravasation is encountered at any point.

In summary, findings from this retrospective analysis and other literature suggests that interferon-alpha holds promise as an intracystic therapy for craniopharyngioma, at the very least for a subset of patients with cystic lesions, with evidence of improved PFS and sustained tumor responses in conjunction with fewer episodes of significant morbidity to date than its predecessors, β-emitting radionucleotides and bleomycin. Interferon therapy can defer definitive surgery or radiotherapy for several years, thereby protecting the developing brain from the deleterious consequences of such conventional treatments. A multinational, global, randomized controlled analysis is now warranted to truly evaluate interferon efficacy versus matched aspiration frequency alone in this setting, in addition to defining the appropriate patients, sustainability of response, drug effect on neighboring cysts or solid craniopharyngioma components if present, and precise toxicity profile from administering interferon by this route. Such prospective multinational clinical trial work is imperative to enhance patient outcome and quality of life while the development of targeted molecular therapies has yet to evolve for this tumor group.

### Supplementary Material

Supplementary material is available at Neuro-Oncology online.

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Document written in accordance with the STROBE guidelines for observational studies.
Conflict of interest statement. All authors declare no conflict of interest.

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