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RESEARCH

Impact of three surgical approaches on the therapeutic efficacy of intraventricular craniopharyngiomas: a single-center retrospective analysis

Yiguang Chen[1,2] · Xiaohai Liu[1,2] · Mingchu Li[1,2] · Yongjian Chen[3] · Hongqi Zhang[1,2] · Ge Chen[1,2]

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Abstract
This study aimed to investigate the therapeutic efficacy of three different surgical approaches for the treatment of intraventricular craniopharyngiomas (IVCs). The three surgical approaches investigated in this study were the endoscopic endonasal approach (EEA), pterional trans-lamina terminalis approach (PTA), and interhemispheric trans-lamina terminalis approach (ITA). Patient demographics, preoperative symptoms, endocrine and hypothalamic status, tumor characteristics, and surgical outcomes were analyzed and compared among the different surgical groups. A total of 31 patients with IVCs were included in the analysis, with 12 patients in the EEA group, 8 patients in the ITA group, and 11 patients in the PTA group. The mean follow-up time was 39 ± 23 months. Statistical analysis of the data revealed significant differences in the gross total resection (GTR) rate among the three surgical groups ($P = 0.033$). The GTR rate for the EEA group was 100%, that for the ITA group was 88%, and that for the PTA group was 64%, which was the lowest rate observed. After surgery, only 8.3% of the patients in the EEA group did not experience new postoperative hypopituitarism, while the percentages in the ITA and PTA groups were 75% and 73%, respectively ($P = 0.012$). Finally, we found that postoperative hypopituitarism may be related to the transection of the pituitary stalk during the operation ($P = 0.020$). Based on the results of this study, we recommend using the EEA and the ITA instead of the PTA for the surgical resection of IVCs. Furthermore, the appropriate surgical approach should be selected based on the tumor's growth pattern.

Keywords Intraventricular · Craniopharyngioma · Endoscopic endonasal · Trans-lamina terminalis · Approach

Introduction

The most obscure and rare type of craniopharyngioma, intraventricular craniopharyngioma (IVC), was first reported by Lobos et al. [1] in 1953, with similar cases reported by subsequent scholars. IVCs have been independently defined since microneurosurgery was introduced by Yasargil et al. [2]. Craniopharyngiomas are benign tumors classified as WHO grade I, which can be theoretically cured after total resection [3, 4]. However, the extent of IVC invasion of the hypothalamus and the third ventricle is significant, and the surrounding structures involved are complex, which requires more rigorous and careful selection of surgical methods. There are still some differences in the choice of surgical approach for IVCs [5–14]. Due to the limited amount of relevant clinical research on the choice of approach for IVCs, we have summarized our institutional experience in selecting the surgical approach for the treatment of this type of craniopharyngioma.

Yiguang Chen and Xiaohai Liu contributed equally to this work and share first authorship.

Hongqi Zhang
xwzhanghq@163.com

Ge Chen
chengecn@139.com

1 Department of Neurosurgery, Xuanwu Hospital Capital Medical University, Beijing, China

2 China International Neuroscience Institute (China-INI), Xuanwu Hospital, Capital Medical University, Xicheng District, Beijing, China

3 Dermatology and Venereology Division, Department of Medicine Solna, Center for Molecular Medicine, Karolinska Institute, Stockholm, Sweden

Methods

Patient selection and identification

This was a retrospective analysis conducted at our single-center institution. The clinical outcomes and characteristics of three surgical approaches were compared: the endoscopic endonasal approach (EEA), pterional trans-lamina terminalis approach (PTA), and interhemispheric trans-lamina terminalis approach (ITA). All cases of postoperative pathology confirmed as craniopharyngioma in the Department of Neurosurgery of Xuanwu Hospital (Capital Medical University, Beijing, China) were collected and compiled from January 2011 to December 2021 (a total of 11 years). We included information only on patients with primary surgical treatment, excluding patients with recurrent tumors and those who had received radiotherapy prior to primary surgery. Patients with extreme cases involving large tumors excessively extending toward the internal carotid arteries or the anterior or posterior skull base were also excluded. Patients with incomplete records or who were lost to postoperative follow-up were also excluded.

According to the definition presented by Pascual et al., the authentic manifestation of IVC should refer to craniopharyngiomas that originate from the infundibular region and grow within the third ventricle—and thus should only include strictly IVCs and not strictly IVCs [15]. Certain criteria must be met for a craniopharyngioma to be defined as an IVC. On preoperative MRI images, the tumor should be observed as primarily occupying the interior of the third ventricle. During surgery, it should be noted that the tumor originates from the upper pituitary stalk or the infundibular region of hypothalamus, and an integrated pituitary stalk or a thickened stalk pushed by the tumor should be noted, as previously mentioned [9]

Based on their preoperative and intraoperative data, a total of 31 patients who met the criteria for IVCs were ultimately selected, including 12 in the EEA group, 8 in the ITA group, and 11 in the PTA group. The case selection process was handled by two senior neurosurgeons and a neuroanatomist. The present study was approved by the Ethics Committee of Xuanwu Hospital. Informed consent was obtained from parents prior to the collection of the clinical data of pediatric patients.

Surgical approach

All surgical operations were performed by neurosurgeons who are considered experts in the field. The surgical techniques and details we followed have been previously described in detail by others in the field [12, 16–20].

Variables and data sources

All patients received routine preoperative consultations with ophthalmologists and endocrinologists as well as psychiatrists, and their vision, visual fields, pituitary endocrine function, and mental status were evaluated in detail. Basic information (age and sex) and clinical data (e.g., symptoms, endocrine status, vision examination results, length of hospital stay, imaging data, complications, and BMI) were recorded retrospectively. The volume and composition of the tumor were collected from the preoperative imaging data, and the volume was calculated according to the following formula: tumor volume $= (A \times B \times C)/2$, where A, B, and C represent the maximum diameter of the tumor in three orthogonal axes. The extent of tumor resection (EOR) was assessed by intraoperative videos and postoperative MRI images. In general, gross total resection (GTR) was defined as 100% tumor resection, near-total resection (NTR) was defined as $\geq 95\%$ and $< 100\%$ resection, and subtotal resection (STR) was defined as $\geq 80\%$ and $< 95\%$ resection. In the first year after surgery, the outpatient follow-up periods were 1 month, 3 months, 6 months, and 1 year, and thereafter, patients were followed up every 6 months or 1 year. The objective assessment at each outpatient follow-up visit included MRI imaging, endocrine hormone testing, ophthalmic testing, BMI measurement, and a psychiatric outpatient consultation. For the detection of the growth hormone (GH) axis, we used IGF-1 and GH levels. New postoperative hypopituitarism was defined as a newly developed hormonal defect after surgery in a patient with normal preoperative endocrine hormone levels. In addition, if a patient had a previous hormonal defect, a new defective hormonal axis was added postoperatively and it was also considered to have new hypopituitarism. Hormone deficits in one or two axes were defined as partial hypopituitarism. Defects in three hormonal axes, with or without dysfunction of the GH axis, were all defined as complete hypopituitarism. We recorded permanent diabetes insipidus (DI) if a patient continued to have polyuria 1 year after surgery or required oral Minirin tablets or desmopressin to maintain a normal urine volume. Hypothalamic dysfunction involves many aspects, including sleep disorders, thermoregulation abnormalities, energy metabolism disturbances, and psychiatric abnormalities [21, 22]. Therefore, to facilitate statistical analysis, the functional status of the hypothalamus in postoperative patients was assessed using a four-point grading scale as follows: grade 1, normal hypothalamic function; grade 2, overweight ($24\ kg/m^2 < BMI \leq 28\ kg/m^2$) and a lack of behaviors indicative of hypothalamic dysfunction; grade 3, obesity ($BMI > 28\ kg/m^2$) or weight gain without hyperphagia or associated changes in emotional behavior or memory; and grade 4, obesity ($BMI > 28\ kg/m^2$) and hyperphagia with cognitive dysfunction, rage behavior, and impaired thirst or disturbances of thermoregulation with sleep–wake disruption or emaciation [23]. The postoperative hospital stay was defined as the time from the first day after surgery to the day of discharge. Recurrence included the development of a tumor after GTR and the progression of a residual tumor after NTR or STR.

Statistical analysis

The Kruskal–Wallis rank sum test was used to compare continuous variables. Independent categorical variables were compared by using the chi-square test or Fisher's exact test. Fisher's exact test was used to compare nonparametric variables between groups. Progression-free survival (PFS) curves and overall survival (OS) curves were generated using the Kaplan–Meier method, and the differences in the recurrence rate and mortality among all groups were evaluated by the log-rank test. The data are expressed as the mean (SD) or number (%). We used the R package survminer to conduct survival analysis, the R package gtsummary for data description and all statistical analyses, and the R package ggplot2 for data visualization and chart plotting (R software version 4.3.1). The P-value ≤ 0.05 was considered to be statistically significant.

Results

General cohort characteristics

From January 2011 to December 2021, a total of 153 patients with craniopharyngioma underwent surgical resection in our hospital. A retrospective analysis of 31 eligible patients was conducted, excluding a total of 117 patients who were confirmed as having non-IVCs based on preoperative imaging and intraoperative videos, as well as patients who had received radiotherapy prior to surgery or experienced recurrence. Data from 5 patients with incomplete information and patients who were lost to follow-up were also excluded (Fig. 1). Based on their preoperative and intraoperative data, all patients who met the criteria for IVCs were ultimately selected, including 12 in the EEA group, 8 in the ITA group, and 11 in the PTA group. Detailed preoperative case grouping, preoperative imaging data, and typical intraoperative visual field maps can be seen in Fig. 2 and Supplementary Table 1. Among all 31 patients with IVCs, there were 12 females and 19 males, with an average age of 44 ± 16 years. The average tumor volume was 10 ± 8 cm^3, and the majority of tumors were cystic (48%) and cystic-solid (39%). According to the postoperative pathological results, there were 11 cases of adamantinomatous craniopharyngioma (ACP) and 20 cases of papillary craniopharyngioma (PCP). The aforementioned basic information did not show statistically significant differences among the three groups. Additionally, there were no significant differences observed in the preoperative BMI values and endocrine symptoms (including DI) among the patients in the three groups. The most common preoperative symptom was visual deterioration, and there were no significant differences observed among the groups (83% vs. 88% vs. 91%, $P > 0.9$). Headache was the second most common symptom, and there was a statistically significant difference observed among the three groups (50% vs. 88% vs. 27%, $P = 0.040$). The remaining baseline information can be found in Table 1.

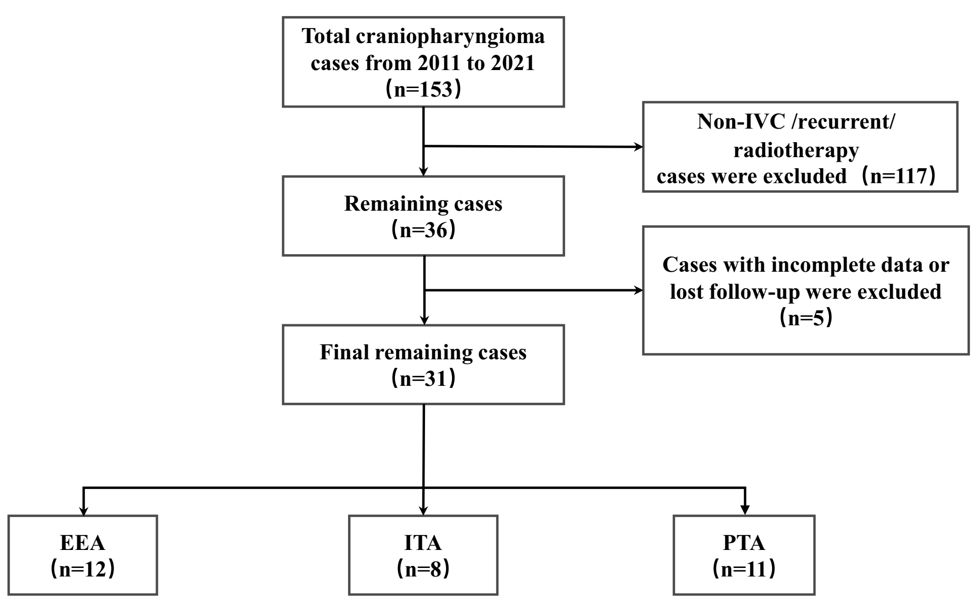


Fig. 1 The flowchart illustrates the process of case selection and exclusion, categorizing them into three different groups based on the surgical approach

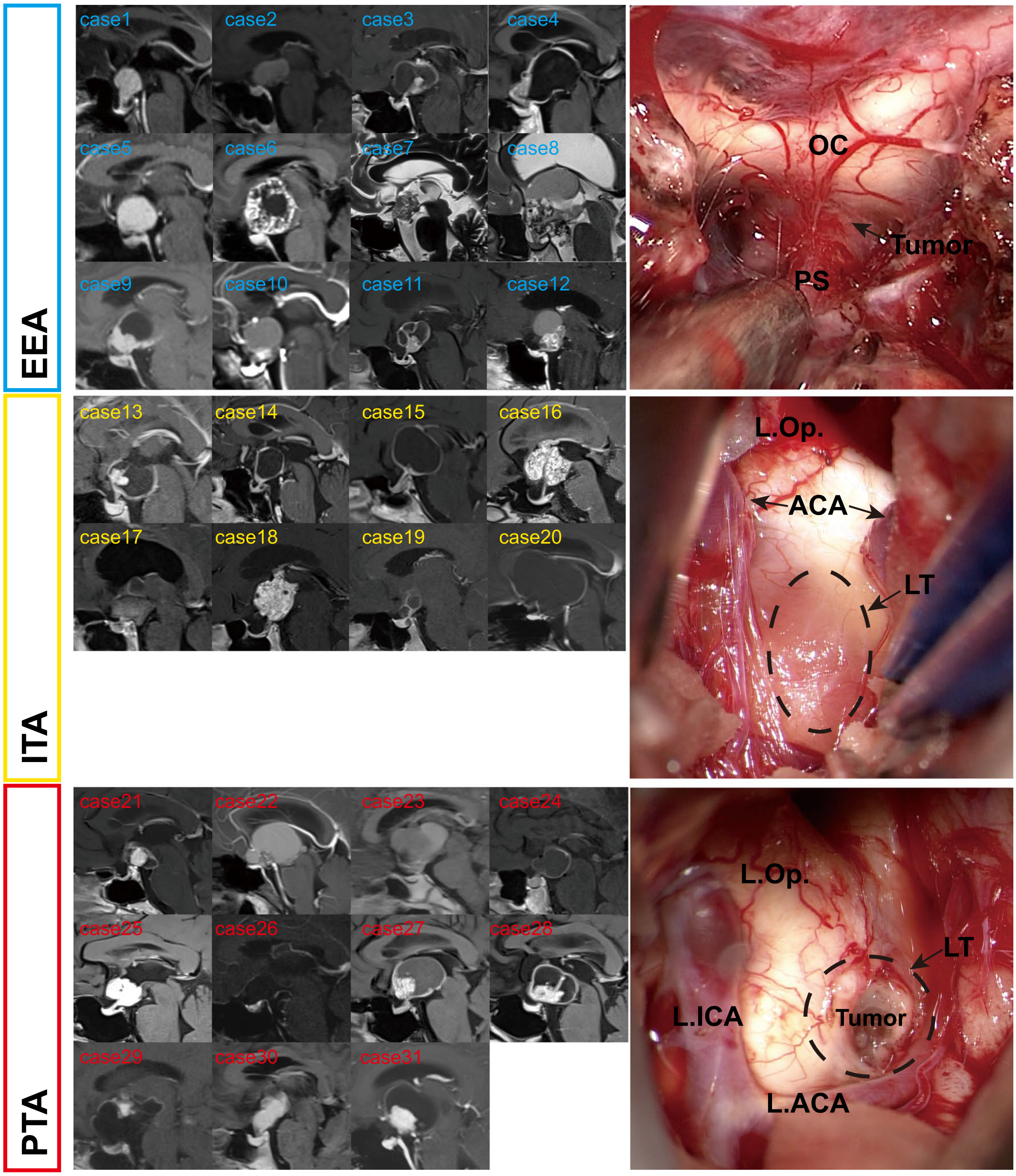


Fig. 2 Preoperative sagittal imaging data and intraoperative typical images for three different surgical approaches. Cases 1 to 12: performing surgery using the EEA. Cases 13 to 20: performing surgery using the ITA. Case21 to 31: performing surgery using the PTA. LT, lamina terminalis; ACoA, anterior communicating artery; ACoC, anterior communicating artery complex; TVF, third ventricular floor; OC, optic chiasm; ICA, internal carotid artery; ACA, anterior cerebral arteries; Op, optic nerves; PS, pituitary stalk; L, left; R, right; EEA, endoscopic endonasal approach; PTA, pterional trans-lamina terminalis approach; ITA, interhemispheric trans-lamina terminalis approach

Surgical outcomes

As shown in Table 2, the overall follow-up time was 39 ± 23 months. The mean follow-up period for the patients in each group was similar (34 ± 21 vs. 35 ± 11 vs. 47 ± 29, $P = 0.7$). The average postoperative hospital stay was 15 ± 6 days, with no statistically significant differences observed in the duration of hospitalization among the three groups (14 ± 6 vs. 18 ± 7 vs. 15 ± 5, $P = 0.5$) (Fig. 3D). All surgeries were performed by three experienced surgeons in the field. They were proficient in performing both open craniotomy and endoscopic surgical

Table 1 Baseline table of 31 patients with intraventricular craniopharyngioma

Variable	Overall ($N=31$)[1]	EEA ($N=12$)[1]	ITA ($N=8$)[1]	PTA ($N=11$)[1]	P-value[2]
Gender					0.7
Female	12 (39%)	5 (42%)	4 (50%)	3 (27%)	
Male	19 (61%)	7 (58%)	4 (50%)	8 (73%)	
Age	44 (16)	47 (14)	37 (17)	45 (16)	0.4
Tumor vol in cm^3	10 (8)	9 (7)	10 (9)	11 (7)	0.5
Tumor composition					0.2
Cystic	15 (48%)	7 (58%)	5 (63%)	3 (27%)	
Solid	4 (13%)	1 (8.3%)	2 (25%)	1 (9.1%)	
Mixed	12 (39%)	4 (33%)	1 (13%)	7 (64%)	
Follow-up in mon	39 (23)	34 (21)	35 (11)	47 (29)	0.7
Preop. BMI	24.73 (3.27)	24.17 (2.85)	25.31 (2.87)	24.97 (4.06)	0.6
Pathology					0.094
ACP	11 (35%)	7 (58%)	1 (12%)	3 (27%)	
PCP	20 (65%)	5 (42%)	7 (88%)	8 (73%)	
Headache	16 (52%)	6 (50%)	7 (88%)	3 (27%)	0.040
Visual disturbance	27 (87%)	10 (83%)	7 (88%)	10 (91%)	>0.9
DI	9 (29%)	5 (42%)	2 (25%)	2 (18%)	0.5
Psychiatric symptoms	7 (23%)	2 (17%)	4 (50%)	1 (9.1%)	0.14
Normal	10 (32%)	4 (33%)	4 (50%)	2 (18%)	0.4
Partial hypopituitarism	20 (65%)	8 (67%)	4 (50%)	8 (73%)	0.6
Complete hypopituitarism	1 (3.2%)	0 (0%)	0 (0%)	1 (9.1%)	0.6

[1]Mean (SD); *n* (%)

[2]Kruskal-Wallis rank sum test; Fisher's exact test

approaches. Regarding the EOR, there were significant differences observed among the three groups ($P=0.033$). The EEA group achieved a GTR rate of 100%. Additionally, the ITA group demonstrated a GTR rate of 88%. However, the PTA group exhibited the lowest GTR rate of 64% (Fig. 3A). Based on the results, more than half of the patients in the EEA group experienced postoperative improvement in visual outcomes (58% vs. 38% vs. 45%). The PTA group exhibited the highest degree of postoperative visual deterioration (17% vs. 13% vs. 27%) (Fig. 3C). However, there were no significant differences in postoperative visual outcomes among the three groups ($P>0.05$). There were significant differences in pituitary endocrine outcomes. The majority of patients in the ITA group (75%) and PTA group (73%) did not experience new hypopituitarism postoperatively. In contrast, only 8.3% of patients in the EEA group had no new hypopituitarism ($P=0.002$) (Fig. 3I). Furthermore, compared to the ITA and PTA groups, in the EEA group, a significant proportion of patients experienced partial hypopituitarism postoperatively (67% vs. 25% vs. 9.1%, respectively, $P=0.012$) (Fig. 3B). It was noteworthy that the EEA group had the highest proportion of patients with intraoperative pituitary stalk transection (75% vs. 25% vs. 27%, $P=0.033$) among the three groups. Additionally, as indicated in Table 3, there was a statistically significant difference in postoperative pituitary function between the group with pituitary stalk transection and the group with pituitary stalk preservation ($P=0.020$). A total of 18 patients (58%) developed permanent DI postoperatively, but there were no significant differences observed among the three groups (58% vs. 63% vs. 55%, $P>0.9$).

There were no significant differences observed among the three groups regarding postoperative hypothalamic function ($P=0.7$). However, it can be noted that in the PTA group, 4 patients were classified as having grade 1 functional status postoperatively (36%), while in the EEA group, only 1 patient was classified as having grade 1 functional status (9.1%). Additionally, one patient in the EEA group was classified as having grade 4 functional status, whereas this condition was not observed in the other two groups (Fig. 3E). Postoperative complications included fever of unknown origin, cerebrospinal fluid (CSF) leak, epistaxis, seizures, hemorrhage, anosmia, and scalp hydrops. However, no significant differences were found in these complications among the three groups.

The overall recurrence rate and mortality rate were both 9.7%, and no significant differences were observed among the three groups ($P=0.8$ vs. $P>0.9$). No significant differences were shown in OS and PFS among the three groups (Fig. 3F–H). Additionally, there were no significant differences observed in the impact of the surgical approach,

Table 2 Postoperative clinical features among three groups

Variable	Overall (N=31)[1]	EEA (N=12)[1]	ITA (N=8)[1]	PTA (N=11)[1]	P-value[2]
Visual outcome					
Improved	15 (48%)	7 (58%)	3 (38%)	5 (45%)	0.7
Unchanged	9 (29%)	2 (17%)	4 (50%)	3 (27%)	0.2
Worsen	6 (19%)	2 (17%)	1 (13%)	3 (27%)	0.7
New hypopituitarism					
None	15 (48%)	1 (8.3%)	6 (75%)	8 (73%)	0.002
Partial hypopituitarism	11 (35%)	8 (67%)	2 (25%)	1 (9.1%)	0.012
Panhypopituitarism	5 (16%)	3 (25%)	0 (0%)	2 (18%)	0.4
Permanent DI	18 (58%)	7 (58%)	5 (63%)	6 (55%)	> 0.9
Hypothalamic status					0.7
Grade 1	6 (20%)	1 (9.1%)	2 (25%)	4 (36%)	
Grade 2	12 (40%)	4 (36%)	3 (37.5%)	4 (36%)	
Grade 3	11 (37%)	5 (45%)	3 (37.5%)	3 (27%)	
Grade 4	1 (3.3%)	1 (9.1%)	0 (0%)	0 (0%)	
Fever of unknown origin	3 (9.7%)	0 (0%)	2 (25%)	1 (9.1%)	0.2
CSF leak	3 (9.7%)	3 (25%)	0 (0%)	0 (0%)	0.10
Epistaxis	2 (6.5%)	2 (17%)	0 (0%)	0 (0%)	0.3
Seizures	1 (3.2%)	0 (0%)	1 (13%)	0 (0%)	0.3
Hemorrhage	1 (3.2%)	1 (8.3%)	0 (0%)	0 (0%)	> 0.9
Anosmia	1 (3.2%)	1 (8.3%)	0 (0%)	0 (0%)	> 0.9
Scalp hydrops	1 (3.2%)	0 (0%)	1 (13%)	0 (0%)	0.3
Death	3 (9.7%)	1 (8.3%)	1 (13%)	1 (9.1%)	> 0.9
Recurrence	3 (9.7%)	2 (16.7%)	0 (0%)	1 (9.1%)	0.8
PFS	37 (23)	30 (19)	35 (11)	46 (30)	0.4
EOR					
GTR	26 (84%)	12 (100%)	7 (88%)	7 (64%)	0.033
NTR	2 (6.5%)	0 (0%)	1 (13%)	1 (9.1%)	0.5
STR	3 (9.7%)	0 (0%)	0 (0%)	3 (27%)	0.049
Postop. hospital stays (days)	15 (6)	14 (6)	18 (7)	15 (5)	0.5
Transected pituitary stalk	14 (45%)	9 (75%)	2 (25%)	3 (27%)	0.033

[1]Mean (SD); *n* (%)

[2]Kruskal-Wallis rank sum test; Fisher's exact test

gender, age, pathology, preoperative endocrine symptoms, or tumor size or composition on the time to death or recurrence (Table 4). The remaining data are presented in Tables 2, 3, and 4.

Discussion

The impact of different surgical approaches on the surgical outcomes of patients with IVCs

Extent of resection

Due to the unique growth location of IVCs, transcranial operation was traditionally used as the sole approach for achieving complete tumor resection prior to the development of endoscopic techniques. However, with the advancement of expanded endonasal endoscopic surgery, excellent resection outcomes have been achieved for patients with suprasellar craniopharyngiomas and even intraventricular craniopharyngiomas [5, 9, 24–28] Our study data also support this perspective, with the EEA group demonstrating the highest rate of GTR compared to the other two groups. This may be attributed to the unobstructed visualization of the third ventricular floor structures and hypothalamus, as there was no blockade from the optic chiasm or ipsilateral optic nerve, making complete resection more feasible with the EEA compared to the PTA or ITA. Furthermore, in the PTA, the presence of significant structures such as the optic nerve on one side and optic chiasm may impede the identification of the interface between the upper segment of the pituitary stalk and the tumor, particularly in the region of the hypothalamic infundibulum. This can potentially lead to residual tumors (Fig. 4A–C).

Visual outcomes

Previous research has consistently shown that the EEA provides superior preservation of visual function for patients [29, 30]. Although our study did not reveal statistically significant differences in visual outcomes among the three groups, it was noteworthy that the EEA group had the highest proportion of patients with postoperative visual improvement, while the ITA group had the lowest proportion. This discrepancy may be attributed to the fact that the blood supply to the optic chiasm primarily arises from the branches of the anterior cerebral artery and the anterior communicating artery [31, 32]. Due to the high incidence of an anomalous anterior communicating artery and its non-fixed relationship with the lamina terminalis, performing a surgical procedure associated with the ITA carries a higher risk of compromising these perforator vessels [33]. While branches of the internal carotid artery and superior hypophyseal artery also supply the lower portion of the optic chiasm, some viewpoints suggest that the blood supply in this region is redundant for the functionality of the optic chiasm. Furthermore, their anatomical locations are relatively fixed, making them identifiable and well protected through the EEA [34].

Endocrine outcomes

In previous research, it has been demonstrated that preserving the pituitary stalk contributes to the postoperative preservation of endocrine function [35, 36]. In this study, most patients in the EEA group exhibited partial pituitary dysfunction postoperatively, and we found that the EEA group had the highest proportion of pituitary stalk transection during surgery. Statistical analysis suggested that the high incidence of pituitary dysfunction in the EEA group may be associated with pituitary stalk transection. This could be because during the EEA for IVC resection, the tumor and the pituitary stalk are typically well visualized from below the third ventricular floor. Additionally, craniopharyngiomas often exhibit significant adhesions to surrounding tissues, making it challenging to identify their borders. Consequently, pituitary stalk transection was frequently required during surgery to achieve GTR.

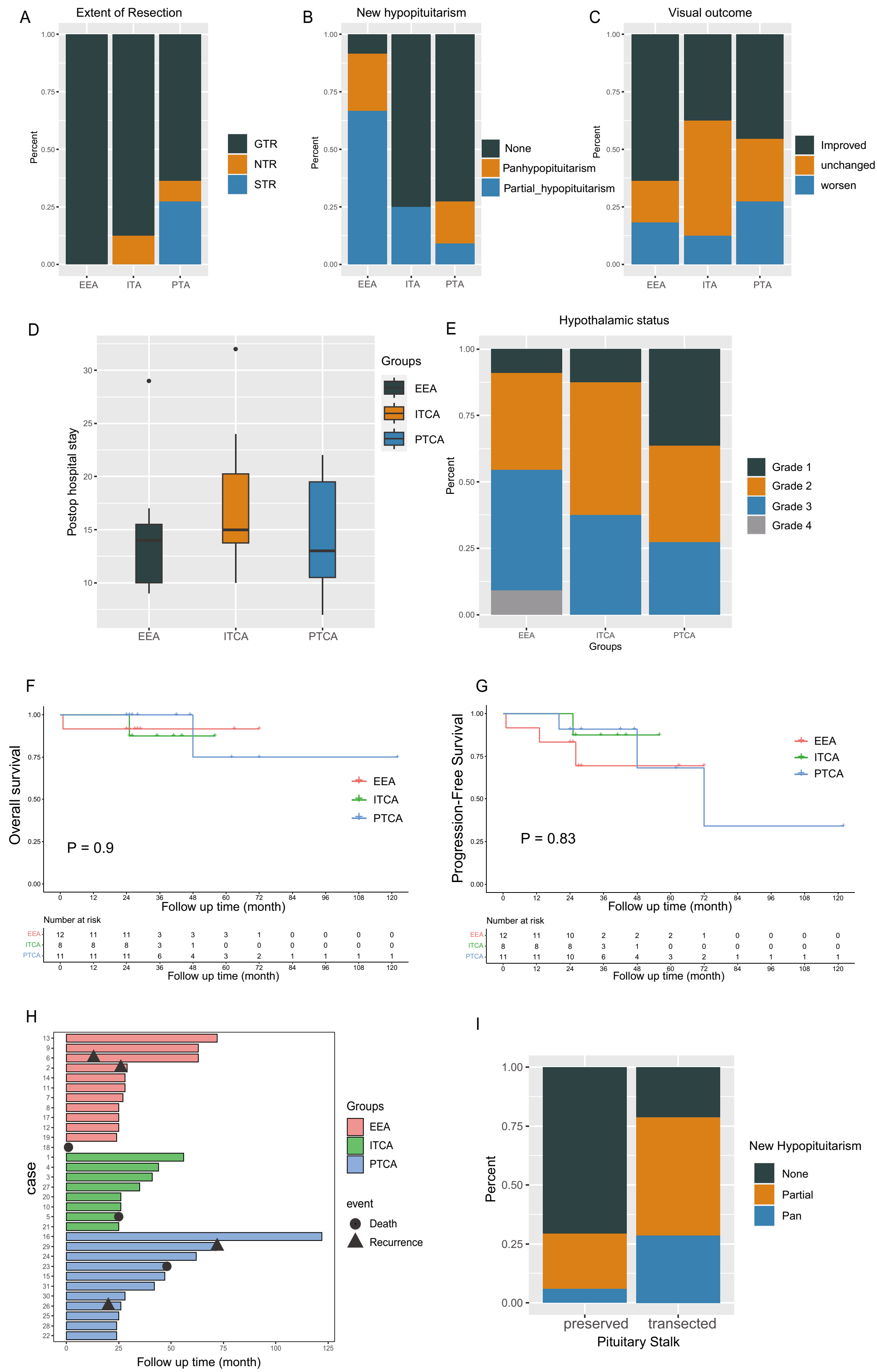
Hypothalamic status

Although there were no statistically significant differences in the scores of hypothalamic status among the three groups, it was evident that the proportion of patients classified as having grade 1 functional status was lowest in the EEA group (9.1% vs. 25% vs. 36%), indicating that a potential significant difference may emerge with a larger sample size. For craniopharyngiomas involving the third ventricle, previous large retrospective studies have suggested that the EEA poses a greater risk of hypothalamic injury compared to than transcranial approaches [37]. This may be attributed to the fact that the EEA for intraventricular tumor resection could exert more disturbance to the hypothalamus and third ventricular floor [38–40]. Particularly for strictly IVCs (pure intraventricular craniopharyngiomas), the EEA inevitably required sharp dissection of a portion of the hypothalamus to establish a pathway for tumor resection, thereby increasing the probability of postoperative hypothalamic injury [26] (Fig. 4G–I).

Other outcomes

We also observed that only in the EEA group, 3 patients experienced CSF leakage. While there were no statistically significant differences between the groups, this still indicates that CSF leakage remains one of the main challenges of EEA [41]. Epistaxis and anosmia were exclusively present in the EEA group [29, 42, 43], and we did not find additional nasal complications in other patients. Other potential complications include nasal mucosal adhesions and empty nose syndrome, which might not be frequently mentioned and could require more attention and intervention from clinical doctors.

Our series of research demonstrated that the GTR rate for the PTA group is only 64%, with four patients failing to achieve complete tumor resection. Interestingly, postoperative imaging data revealed that the majority of residual tumors were concentrated in the retrochiasmatic region and the anterior region of the third ventricle floor (Supplementary Fig. 1). In a previous series of studies, 8 cases of intraventricular craniopharyngioma underwent surgical treatment via the PTA [12]. Among this, 1 patient experienced recurrence, with the recurrent tumor's location also being suggested to be in the retrochiasmatic region. We now believe that the PTA approach may result in residual tumors and recurrences in this location due to a lack of visualization of the hypothalamus, particularly the visualization of the ipsilateral hypothalamus. In contrast, the ITA directly provides a significant advantage in terms of midline orientation to access the third ventricle through the lamina terminalis, offering better visualization of both the bilateral walls of hypothalamic and third ventricle, which can contribute to the safe complete resection of tumors [44].


A
Extent of Resection
Percent
EEA
ITA
PTA
GTR
NTR
STR
B
New hypopituitarism
None
Panhypopituitarism
Partial_hypopituitarism
C
Visual outcome
Improved
unchanged
worsen
D
Postop hospital stay
Groups
EEA
ITCA
PTCA
E
Hypothalamic status
Grade 1
Grade 2
Grade 3
Grade 4
Groups
F
Overall survival
P = 0.9
Follow up time (month)
Number at risk
G
Progression-Free Survival
P = 0.83
H
case
event
Death
Recurrence
I
New Hypopituitarism
Partial
Pan
preserved
transected
Pituitary Stalk

◂**Fig. 3** Patient surgical outcomes and postoperative clinical characteristics. **A**–**E** Using bar charts and box plot to represent the major postoperative evaluation indicators among the three different groups of patients. **F**–**H** Kaplan–Meier curves and swimmer plot were used to compare the overall survival (OS) and progression-free survival (PFS) of IVC treatment among three different surgical approaches. **I** The relationship between newly developed postoperative endocrine symptoms and intraoperative pituitary stalk integrity

Approach selection

The primary goal of surgical treatment for primary craniopharyngiomas, especially for the first surgery, is to achieve maximal possible and safe tumor resection.

IVCs, due to their growth direction in the central region of the skull base, are more likely to be treated using the EEA and the ITA. This preference approach selection was supported by our research results, which demonstrated comparable rates of GTR and superiority of the EEA and ITA over the PTA. In terms of selecting between these two approaches, based on our previous experience from a single center, we emphasized the importance of evaluating preoperative imaging data and ensuring thorough preoperative preparation.

Due to its inherent advantages and the ability to maneuver the endoscope for close-range observation, the EEA provides clearer exposure of the third ventricular floor and hypothalamus. This enhanced visualization can aid in the identification and resection of lesions at the origin point of the craniopharyngioma, facilitating more thorough tumor removal. Therefore, complete resection using the EEA can be attempted for the majority of IVCs, especially when preoperative imaging suggests tumor involvement extending downward toward the pituitary stalk. This location is often not directly visualized with the ITA.

However, in rare cases, the tumor might be predominantly located at the optic recess of the third ventricle, pushing the optic chiasm toward the pituitary stalk. This severely compresses the available space in the suprachiasmatic corridor, making endoscopic instrument manipulation challenging. Indeed, in such cases, there can be significant adhesions between the tumor and the optic chiasm, making it highly challenging to perform endoscopic procedures without causing potential damage to the nerves. The choice of the surgical approach should account for these factors and prioritize patient safety and optimal tumor resection while minimizing potential complications. Therefore, in these situations, the ITA should be recommended. This approach allows for the utilization of expansion of the lamina terminalis by the tumor pushing forward, which facilitates microscopic surgical manipulation. However, there are reports suggesting the use of the EEA through the suprachiasmatic corridor for surgery [10]. We believe that this is not a routine surgical approach, and certain considerations need to be taken into account. These include the potential disruption of the blood supply above the optic chiasm and the obstruction of the surgical visual field by the anterior communicating artery complex. We also highly advocate for the utilization of the ITA when the preoperative imaging data clearly identify a well-defined intraventricular craniopharyngioma located strictly within the third ventricle and the presence of an intact pituitary stalk and a fully visible, intact floor of the third ventricle is demonstrated in the sagittal images (Fig. 4E). Since these tumors are most likely to grow solely within the interior of the third ventricle without extending beyond its floor, utilizing the lamina terminalis corridors allows for a more direct approach to the main body of the tumor. This approach enables the preservation of the intact bottom of the third ventricle and the structures of the hypothalamus postoperatively (Fig. 4F), thereby reducing the likelihood of disturbing and damaging the hypothalamic nuclei and the perforating vessels that supply them. Additionally, this approach facilitates the complete preservation of the connection between the pituitary stalk and the hypothalamus. However, when using the ITA, the anterior communicating complex might partially obstruct the visual field and interfere with the surgical procedure. If necessary, the anterior communicating artery can be dissected during surgery to create a larger operating space [45, 46]. Therefore, a thorough assessment of the preoperative vascular condition, such as MRA, CTA, or DSA, is essential to determine the position of the anterior communicating artery and the status of the anterior cerebral circulation. This assessment would also ensure adequate preparation for the potential need to interrupt the anterior communicating artery during the procedure.

Finally, we designed model diagrams to briefly explain the typical situation of two different approach selections (Fig. 4J–L).

Limitations

This study involved multiple surgeons performing the surgeries, which introduced the potential influence of intraoperative bias and other factors. Furthermore, although the GTR rate was higher in the EEA group than in the other two groups, there was no significant statistical difference in terms of the recurrence rate or mortality rate. On the one hand, this might be attributed to the small sample size; on the other hand, it is possible that the limited follow-up time could contribute to the lack of

Table 3 Postoperative pituitary function

Variable	N	Overall (N = 31)[1]	Preserved (N = 17)[1]	Transected (N = 14)[1]	P-value[2]
New hypopituitarism	31				0.020
None		15 (48%)	12 (71%)	3 (21%)	
Partial		11 (35%)	4 (24%)	7 (50%)	
Pan		5 (16%)	1 (5.9%)	4 (29%)	

[1]n (%)

[2]Fisher's exact test

Table 4 Overall survival and progression-free survival of 31 patients

	Tumor response			Time to death		
Characteristic	HR[1]	95% CI[1]	P-value	HR[1]	95% CI[1]	P-value
Groups						
EEA	—	—		—	—	
ITCA	0.45	0.05, 4.44	0.5	1.81	0.11, 30.6	0.7
PTCA	0.86	0.17, 4.50	0.9	0.79	0.05, 14.0	0.9
Gender	2.13	0.47, 9.75	0.3	0.54	0.04, 7.05	0.6
Age	1.01	0.94, 1.08	0.9	1.13	0.86, 1.47	0.4
Tumor_vol_in_cm3	0.98	0.87, 1.11	0.8	1.63	0.58, 4.62	0.4
Tumor_consistency	1.01	0.40, 2.54	> 0.9	0.05	0.00, 10.8	0.3
Preop_BMI	1.02	0.76, 1.36	0.9	1.57	0.64, 3.84	0.3
Pathology	0.52	0.11, 2.41	0.4	0.36	0.03, 4.30	0.4
Headache	0.83	0.12, 5.65	0.8	0.01	0.00, 79.4	0.3
Visual_disturbance	0.50	0.06, 4.62	0.5	0.00	0.00, Inf	> 0.9
DI	1.52	0.27, 8.41	0.6	0.00	0.00, Inf	> 0.9
Hypopituitarism						
Normal	—	—		—	—	
Partial_hypopituitarism	1.07	0.20, 5.66	> 0.9	1.07	0.09, 12.3	> 0.9
Complete_hypopituitarism	0.00	0.00, Inf	> 0.9	0.00	0.00, Inf	> 0.9

[1]*HR* hazard ratio, *CI* confidence interval

significant differences. Patients who did not achieve complete resection postoperatively may have been promptly referred to the Functional Neurosurgery Department for additional treatments such as gamma knife radiosurgery. This treatment approach could potentially delay the probability and timing of recurrence. Longer follow-up periods are necessary to accurately assess the impact of different treatment strategies on recurrence rates and overall outcomes. Given the retrospective study design, there is the potential for selection bias and incomplete data. Furthermore, the utilization of data solely from a single center imposes limitations on the generalizability of the study findings. Hence, further multicenter prospective studies are warranted to validate and refine these findings, aiding in the optimization of surgical strategies for managing IVCs.

Conclusions

Based on the results of this study, we recommend using the EEA and the ITA instead of the PTA for the surgical resection of IVCs. Although the EEA has been proven to have a higher GTR rate for IVCs, it may result in a higher incidence of new hypopituitarism, possibly related to the intraoperative transection of the pituitary stalk. Furthermore, the appropriate surgical approach should be selected based on the tumor's growth pattern. In most cases, the EEA can be applied for IVCs, especially when the tumor extends down to involve the upper segment of the pituitary stalk. However, when the pituitary stalk and the third ventricle floor are intact or when the suprachiasmatic corridor was too narrow, the ITA should be used to ensure complete tumor resection while minimizing additional damage to the hypothalamus.

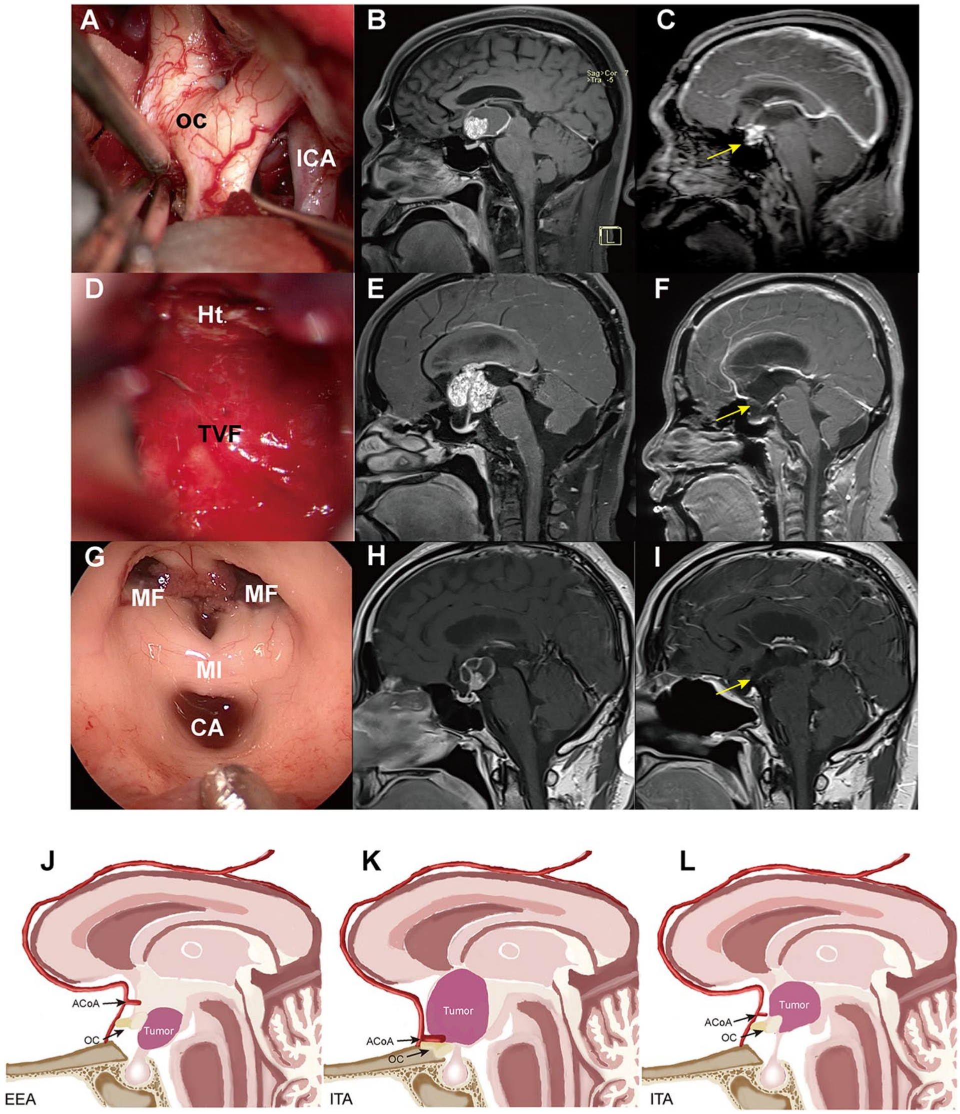


Fig. 4 The impact of three surgical approaches on the hypothalamus. **A**–**C** In case 27, surgery was performed using the PTA; **A** due to the obstruction of the optic chiasm during the surgery, it posed challenges for the exploration of the hypothalamus; **C** there was residual tumor in the infundibular region of the hypothalamus (yellow arrow) after the procedure. **D**–**F** In case 16, the surgery was performed using the ITA. Preoperative imaging data indicated that the tumor was completely located within the third ventricle; **D** intraoperatively, after complete tumor resection, the intact floor of the third ventricle could be observed, along with the view of the hypothalamus; **F** follow-up MRI after the surgery showed the integrity of the hypothalamic structures and the third ventricle floor (yellow arrow). **G**–**I** In case 11, the surgery was performed using the EEA. Preoperative imaging data indicated that the tumor was completely located within the third ventricle; **G** intraoperatively, after complete tumor resection, the internal structures of the third ventricle could be observed; **I** postoperative follow-up MRI revealed the destruction of hypothalamic structures and the third ventricle floor (yellow arrow). **J**–**L** Typical diagram for surgical approach selection; **J** the tumor invading the upper segment of the pituitary stalk, with the main body located behind the optic chiasm, was suitable for surgical intervention using the EEA; **K** the tumor primarily located within the third ventricle, with the intact floor of the third ventricle and pituitary stalk, along with significant compression of the optic chiasm causing reduced space below it, was suitable for surgical intervention using the ITA; **L** the tumor located within the third ventricle, with intact floor of the third ventricle and pituitary stalk, was suitable for surgical intervention using the ITA to ensure the best possible preservation of the integrity of the hypothalamus, as well as the continuity between the hypothalamus and pituitary stalk. EEA, endoscopic endonasal approach; ILTA, interhemispheric trans-lamina terminalis approach; OC, optic chiasm; LT, lamina terminalis; TVF, third ventricular floor; MI, massa intermedia; MF, Monra's foramen; CA, cerebral aqueduct; Ht., hypothalamus; ACoA, anterior communicating artery

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Author contribution G. C. conceived and designed and guided the writing of the original article. YG. C. completed the figures and tables and wrote the article. X. L. and YJ. C. summarized and analyzed the data. M. L. assisted in writing the papers. H. Z. supervised the writing process of the article. All authors read and approved the final manuscript.

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Data availability Not applicable.

Declarations

Ethics approval and consent to participate This retrospective study was approved by the Ethics Committee of Xuanwu Hospital, Capital Medical University, Beijing, China. Informed consent was obtained from all individual participants included in the study.

Competing interests The authors declare no competing interests.

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