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The influence of tumor topography on the surgical outcome of craniopharyngiomas

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OBJECTIVE Various topographical classifications for craniopharyngioma have been proposed based on their relationship with optic chiasm and the third ventricular floor. There is a paucity of literature evaluating the surgical outcome based on tumor topography. This study aims to compare the surgical outcomes of retrochiasmatic craniopharyngiomas (RCPs) and nonretrochiasmatic craniopharyngiomas (non-RCPs).

METHODS This retrospective study includes newly diagnosed patients with craniopharyngioma who underwent surgery between January 2000 and December 2015. Clinical features, the extent of resection (EOR), surgical outcomes, tumor recurrence, and progression-free survival (PFS) of craniopharyngiomas were compared with respect to their relationship to the optic chiasm and third ventricular floor.

RESULTS The authors identified RCPs in 104 and non-RCPs in 33 patients. RCPs were significantly larger and more associated with hydrocephalus than were non-RCPs ($p < 0.001$) at the time of diagnosis. Puget grade 2 hypothalamic involvement was more frequent with RCPs. EOR and PFS following either subtotal resection ($p = 0.07$) or gross-total resection ($p = 0.7$) were comparable between RCPs and non-RCPs. There was no significant difference in the postoperative visual outcome. Resection of RCPs resulted in higher postoperative hypopituitarism (64% vs 42%, $p = 0.01$) and hypothalamic dysfunction (18% vs 3%, $p = 0.02$). Location of the tumor, either retrochiasmatic (HR 0.5; 95% CI 0.14–2.2; $p = 0.4$) or nonretrochiasmatic (HR 1.3; 95% CI 0.3–5.5; $p = 0.6$), did not show association with recurrence. RCPs with extra- and intraventricular components (type 3b) had a higher incidence of postoperative hypothalamic morbidities ($p = 0.01$) and tumor recurrence (36% vs 19%; $p = 0.05$) during follow-up than the extraventricular (type 3a) RCP. Between prechiasmatic and infrachiasmatic/intrasellar craniopharyngiomas, EOR ($p = 0.7$), postoperative diabetes insipidus ($p = 0.4$), endocrinological outcome ($p = 0.7$), and recurrence ($p = 0.1$) were comparable. The patients with complex multicompartmental tumors had a lower rate of gross-total resection (25%, $p = 0.02$) and a higher incidence of tumor recurrence (75%, $p = 0.004$) than the rest.

CONCLUSIONS The tumor topography can influence the postoperative outcome. RCPs can be associated with a higher incidence of hypopituitarism and hypothalamic morbidities postoperatively. The influence of topography on EOR and tumor recurrence is controversial. However, this study did not find a significant difference in EOR and tumor recurrence between RCPs and non-RCPs. PFS and overall mortality are also comparable.

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KEYWORDS craniopharyngioma; topography; optic chiasm; surgical outcome; tumor

Craniopharyngiomas constitute 2.5%–3% of all intracranial tumors.[1] They are WHO grade I tumors arising from the ectopic remnants of the epithelial cells derived from Rathke's pouch. Resection of these tumors often results in significant postoperative morbidities due to the surrounding critical neurovascular structures like the optic pathway, hypothalamus, and the circle of Willis and its perforators.[2–8] Resection of craniopharyngioma remains challenging despite advancements in microsurgical techniques. Over the last 2 decades, there has been a paradigm shift toward conservative resection with more emphasis on maintaining the quality of life of these patients. The strategy of maximal safe resection and adjuvant radiotherapy (RT) for the residual tumor has been reported to be equally effective in local tumor control and visual, endocrinological, and hypothalamic outcomes.[9,10] Factors

ABBREVIATIONS DI = diabetes insipidus; EEA = endonasal endoscopic approach; EOR = extent of resection; GTR = gross-total resection; ICP = intracranial pressure; KM = Kaplan-Meier; PFS = progression-free survival; RCP = retrochiasmatic craniopharyngioma; RT = radiotherapy; STR = subtotal resection; TCA = transcranial approach; 3VF = third ventricular floor.

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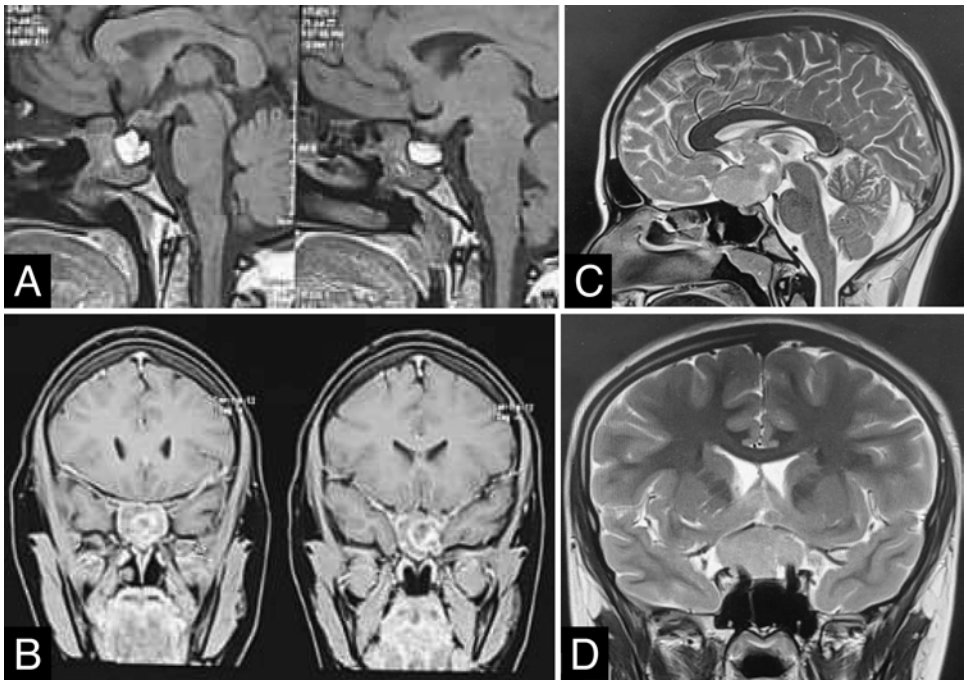

FIG. 1. Topographic classification of craniopharyngiomas on MRI. Preoperative T1-weighted sagittal (**A**) MRI shows an intrasellar (type 1) hyperintense cystic craniopharyngioma, and T1-weighted postcontrast coronal (**B**) MRI shows intrasphenoidal craniopharyngioma. T2-weighted sagittal (**C**) and coronal (**D**) MRI sequences show prechiasmatic craniopharyngioma (type 2).

like tumor size, hydrocephalus, hypothalamic dysfunction at presentation, and imaging evidence of hypothalamic involvement by the tumor may help predict postoperative morbidities and, thereby, the extent of resection (EOR).[11–14]

Various topographical classifications have been proposed based on the tumor's relation with diaphragma sellae, optic chiasm, pituitary stalk, and the third ventricular floor (3VF).[15–19] The ectopic epithelial cells that give rise to craniopharyngioma can rest along the pituitary stalk from the pituitary gland to the tuber cinereum on the 3VF. Based on the site of origin and growth axis, craniopharyngiomas can be divided into intrasellar, prechiasmatic, retrochiasmatic, purely intraventricular, and multicompartmental giant tumors.[17,18] Except for intrasellar and intraventricular tumors, the other variants can be partially intra- and extraventricular or extraventricular alone. The tumor's location in relation to the optic chiasm and 3VF decides the surgical approach.[15,18,19] Its relation to critical neurovascular structures may also affect the EOR and postoperative outcomes. There is a paucity of literature evaluating the surgical outcome of craniopharyngiomas based on their topography. This study aims to analyze the surgical outcome of retrochiasmatic craniopharyngiomas (RCPs) following transcranial approaches (TCAs) and to compare it with nonretrochiasmatic craniopharyngiomas (non-RCPs).

Methods

Patients who underwent surgery between January 2000 and December 2015 were included in this study. The study included only newly diagnosed patients with craniopharyngioma—individuals who had undergone surgery for recurrent craniopharyngiomas were excluded from the study. All patients underwent CT, MRI of the brain, and evaluation of the hormonal profile. Visual acuity and visual field were assessed using computerized perimetry preoperatively. Clinical presentation, radiological and intraoperative findings, postoperative neurological status, and postoperative imaging were recorded in the case files. The diagnosis of craniopharyngioma was made based on the clinical and radiological findings and confirmed postoperatively by histopathological examination of specimens obtained in all patients.

The tumor location, size (measured along the longest axis), extension into various compartments, texture, calcification, presence of hydrocephalus, and relation to the 3VF were obtained from preoperative CT and MRI scans. We graded hypothalamic involvement by craniopharyngioma using the Puget grading system on preoperative MRI.[20] Two authors (S.S. and G.M.) independently assessed the preoperative MRI and intraoperative findings regarding the tumor's relation with optic nerves, optic chiasm, A1 segment of the anterior cerebral artery, and 3VF, and classified the lesions as intrasellar/infrachiasmatic (type 1; Fig. 1A and B), prechiasmatic (type 2; Fig. 1C and D), retrochiasmatic (type 3; Fig. 2A–D), intraventricular (type 4; Fig. 2E), and complex multicompartmental (type 5; Fig. 2F) craniopharyngiomas. The interrater reliability was 87.2%. This study grouped prechiasmatic, infrachiasmatic, and intraventricular craniopharyngiomas as non-RCPs. The surgery was considered a subtotal resection (STR) when there was any visible tumor residue, including calcification intraoperatively, and confirmed if there was a soft-tissue mass lesion with contrast enhancement in the postoperative MRI study. The rest of the patients were

considered to have received gross-total resection (GTR), including those (6 patients) who had microcalcifications (< 2 mm) on follow-up CT scans. During follow-up, the neurological status, vision, and hormonal status of the patient were evaluated. Apart from an immediate postoperative CT scan of the brain performed within 24 hours of surgery, all patients were evaluated with CT and MRI of the brain 3–6 months after the surgery to assess the presence of any residual lesion. Death occurring within 30 days of definitive surgery was considered to be surgery related.

Statistical Analysis

Descriptive statistics for quantitative variables included mean, median, and standard deviation. Categorical variables were described as frequencies and proportions. A comparison of various clinical characteristics between study subjects was made using Pearson's chi-square or Fisher's exact test. An independent-samples t-test was used to compare the continuous variables. Progression-free survival (PFS) was calculated using the Kaplan-Meier (KM) survival curve. The hazard ratio was calculated using Cox's proportional hazard analysis to predict the factors associated with tumor recurrence. The odds ratio was calculated using the logistic regression analysis to identify the predictor variables for the EOR. All statistical tests were 2-tailed, and a p value < 0.05 was considered statistically significant. We used statistical package R with RStudio (version R-4.2.1) to conduct all statistical tests.

Results

Between January 2000 and December 2015, 176 patients were operated on for craniopharyngioma. Among these 176 patients, 158 had undergone resection of newly diagnosed craniopharyngiomas; 9 of them were lost to follow-up. Among the remaining 149 patients, we identified RCPs in 104 (70%). Thirty-three patients (22%) had non-RCPs. Among these 33 patients with non-RCP, 21 (14%) had prechiasmatic and 10 (6.7%) had infrachiasmatic craniopharyngiomas. Two patients (1.3%) had pure intraventricular craniopharyngiomas. Multicompartmental tumors were found in 12 patients (8%). Eighteen patients underwent resection for recurrent craniopharyngiomas.

Clinical Presentation

Table 1 shows the demographic and clinical features of the patients with RCP and non-RCP. Among 104 patients with RCP, 69 (66%) were males, and 35 (34%) were females. The mean age of the patients with retrochiasmatic tumors at presentation was 27.4 years, whereas those with nonretrochiasmatic tumors had a mean age of 23.8 years. The patients with RCP had impaired vision in 53.8%, whereas 82% of those with non-RCP had visual impairment at presentation ($p < 0.001$). Symptoms of raised intracranial pressure (ICP) were present in 36.5% and 9% of the patients with RCPs and non-RCPs, respectively ($p < 0.001$). There was no significant difference in other symptoms between them. Impaired vision and symptoms of raised ICP were present in 75% and 58% of patients with multicompartmental tumors, respectively. The patients with multicompartmental tumors also frequently presented with raised ICP symptoms compared to those with non-RCPs (58% vs 9%, $p = 0.001$), while the incidence of other symptoms was comparable.

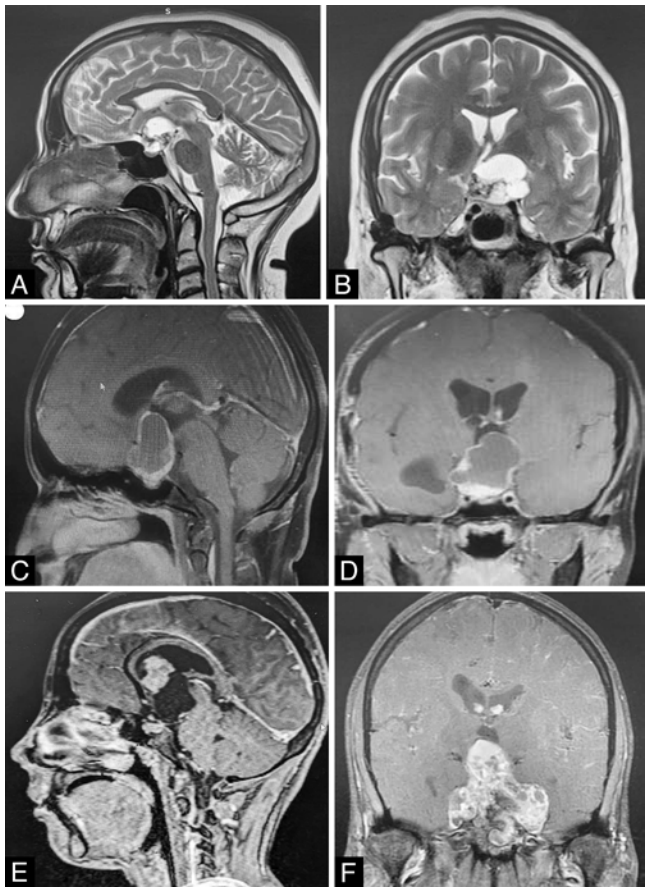

FIG. 2. Topographic classification of craniopharyngiomas. Preoperative T2-weighted sagittal (**A**) and coronal (**B**) MRI sequences show retrochiasmatic extraventricular craniopharyngioma (type 3a). Sagittal (**C**) and coronal (**D**) postcontrast T1-weighted MRI sequences show retrochiasmatic, extra- and intraventricular (type 3b) craniopharyngioma. T1-weighted sagittal (**E**) MRI sequence with Gd enhancement shows pure intraventricular tumor (type 4). Postcontrast T1-weighted coronal (**F**) MRI sequence shows multicompartmental craniopharyngioma (type 5) with bilateral parasellar and clival components.

Neuroradiology

Table 1 also compares the imaging features of the patients with RCPs and non-RCPs. The RCPs were found to be larger than the non-RCPs; tumor size was > 3 cm in 67.3% of the RCPs, whereas the majority (66.7%) of non-RCPs were ≤ 3 cm ($p < 0.001$). When we compared RCPs with prechiasmatic craniopharyngiomas alone, the RCPs were still significantly larger ($p = 0.01$). Retrochiasmatic and multicompartmental tumors had a higher incidence of hydrocephalus (54.8% and 50%, respectively) than did the non-RCPs (18%). Puget grade 2 hypothalamic involvement was seen in 43% of patients with RCPs, whereas it was limited to grade 0 and 1 in 90% of the non-RCP cohort ($p = 0.001$). The difference in the radiological evidence of hypothalamic involvement remained significant between

TABLE 1. Demographics, clinical presentation, and imaging features in 137 patients with RCPs and non-RCPs

Characteristic	RCP Group, n = 104	Non-RCP Group, n = 33	p Value
Mean age in yrs (± SD)	27.4 (± 17.2)	23.8 (± 17)	0.12
Sex			
Male	69 (66)	22 (66.7)	0.76
Female	35 (34)	11 (33.3)	
Impaired vision	56 (53.8)	27 (82)	<0.001
Raised ICP Sxs	38 (36.5)	3 (9)	<0.001
Behavioral disturbances	17 (16)	3 (9)	0.19
Memory disturbances	13 (12.5)	3 (9)	0.45
Polyphagia/polydipsia	23 (22)	4 (12)	0.09
Growth retardation	7 (6.7)	3 (9)	0.7
Sxs of hypothalamic involvement	26 (25)	6 (18)	0.3
Seizures	6 (6)	3 (9)	0.43
Mean duration of Sxs (± SD) in mos	13.16 (± 15.5)	7.7 (± 7.4)	0.04
Fundus			
Normal	53 (51)	6 (18)	<0.001
Optic atrophy	27 (26)	15 (45.5)	
Papilledema	24 (23)	2 (6)	
Calcification			
Absent	19 (18.2)	5 (15.2)	
Specks	41 (39.4)	14 (42)	0.4
Rim	24 (23)	10 (30)	
Extensive	20 (19.2)	4 (12)	
Location			
Sella–suprasellar	21 (20.2)	15 (45.5)	<0.001
Suprasellar	83 (79.8)	13 (39.4)	
Hydrocephalus	57 (54.8)	6 (18)	<0.001
Size of tumor			
≤3 cm	34 (32.7)	22 (66.7)	<0.001
3.1–5 cm	61 (58.7)	7 (21)	
>5 cm	9 (8.6)	4 (12)	
Puget grade			
0	0	10 (30)	
1	59 (56.7)	20 (61)	<0.001
2	45 (43.3)	3 (9)	

Sxs = symptoms.
Values are expressed as the number of patients (%) or the mean (± SD).

the two groups even after excluding the intrasellar/infrachiasmatic variants, which had grade 0 hypothalamic involvement (p = 0.01). Grade 2 hypothalamic involvement was also more common in multicompartmental tumors (50%) than in non-RCPs. Sellar extension of the tumor was more commonly found in patients with prechiasmatic craniopharyngioma (48%, p = 0.01) than in those with RCPs, which remained predominantly suprasellar (71%).

Extent of Resection

Table 2 shows the approaches we used in this series. We often used the pterional approach to resect RCPs (85%) and non-RCPs (52%). Table 2 also compares the EOR and tumor recurrence among the patients with RCP and non-RCP. GTR and STR were achieved in 61 (59%) and 43 (41%) patients with RCP, respectively. Eleven patients received adjuvant RT after STR. GTR was achieved in 70% of the patients with non-RCP. No significant difference was found in the EOR between the two groups (p = 0.25). The patients with multicompartmental tumors had a lower GTR (25%, p = 0.02) and a higher incidence of tumor recurrence (75%, p = 0.004) than the rest.

On logistic regression analysis, tumor location (OR 0.56, 95% CI 0.15–1.9; p = 0.3); size (OR 1.3, 95% CI 0.79–2.45; p = 0.2); Puget grade (OR 1.2, 95% CI 0.63–2.64; p = 0.4); hydrocephalus (OR 1.07, 95% CI 0.55–2.10; p = 0.8);

TABLE 2. Surgical approaches, EOR, histopathology, neurological, endocrinological, and oncological outcomes for RCPs and non-RCPs

Variable	RCP Group, n = 104	Non-RCP Group, n = 33	p Value
TCAs			
Pterional	88 (85)	17 (52)	
FTOZ	5 (4.8)	0	
Bifrontal interhemispheric	2 (2)	2 (6)	NA
Transcallosal	2 (2)	2 (6)	
Transpetrosal	1 (1)	0	
EEA	6 (6)	12 (36)	
GTR	61 (58.6)	23 (69.7)	0.25
STR	32 (30.7)	10 (30.3)	
STR + RT	11 (10.6)	0	
Immediate postop vision			
Same	51 (49)	13 (39)	
Improved	43 (41.3)	15 (45.5)	0.35
Worsened	10 (9.6)	5 (15)	
Postop cranial nerve deficits	10 (9.6)	2 (6)	0.29
Postop motor deficit	13 (12.5)	3 (9)	0.36
DI/SIADH secretion	76 (73)	19 (57)	0.05
Hypopituitarism	67 (64.4)	14 (42)	0.01
Hypothalamic dysfunction	19 (18.3)	1 (3)	0.02
Postop shunt requirement	7 (7)	1 (3)	0.41
Op-related death	5 (4.8)	1 (3)	0.6
Overall recurrence*	27/99 (27.3)	14/32 (43.7)	0.08
Recurrence after STR†	18/32 (56.3)	8/10 (80)	0.17
Recurrence after GTR†	9/61 (14.8)	6/23 (26.1)	0.22
2-, 5-, & 10-yr PFS after GTR	93.4%, 87.5%, 72%	94.4%, 94%, 58.8%	0.7
2-, 5-, & 10-yr PFS after STR	75.6%, 61.2%, 52.7%	50%, 41.7%, 41%	0.07
Histopathology			
Papillary	13 (12.5)	3 (9)	0.5
Adamantinomatous	89 (85.5)	30 (91)	
Mixed	2 (2)	0	
2-, 5-, & 10-yr PFS for adamantinomatous CPs	93%, 73%, 60%	90%, 68%, 38%	0.18
2-, 5-, & 10-yr PFS for papillary CPs	100%, 77%, 77%	100%, 100%, 100%	0.48

CP = craniopharyngioma; FTOZ = frontotemporal orbitozygomatic; NA = not applicable; SIADH = syndrome of inappropriate antidiuretic hormone.
Unless otherwise indicated, values are expressed as the number of patients (%).
* Five patients in the RCP group and 1 in the non-RCP group who died after operation are not counted.
† Denominators for patients with GTR and those with STR are given for clarity.

and symptoms of hypothalamic dysfunction (OR 1.3, 95% CI 0.62–2.82; p = 0.4) did not predict the EOR. GTR was achieved in 60% and 80% of patients with adamantinomatous and papillary craniopharyngiomas, respectively. There was a trend toward better GTR in papillary craniopharyngiomas (p = 0.09). Although the histopathological subtype of craniopharyngioma predicted the EOR on univariate analysis (OR 0.8274, 95% CI 0.26–2.62; p = 0.03), it failed to predict EOR on multivariate logistic regression analysis (p = 0.7).

Postoperative Complications

Table 2 also describes the postoperative complications in patients with RCP and non-RCP. Among the patients with RCP, 42% experienced improvement and 9% experienced worsening of preoperative vision after surgery. There was no significant difference in the visual outcome (p = 0.3) and other postoperative neurological complications between RCPs and non-RCPs. Postoperatively, 73% of patients with RCP experienced diabetes insipidus (DI) compared to 57.5% of non-RCP patients (p = 0.05). Resection of RCPs also resulted in more postoperative hypopituitarism than non-RCPs (64% vs 42%, p = 0.01). The patients with RCP had a higher incidence (18%) of postoperative hypothalamic dysfunctions like abnormal weight gain and sleep–wake cycle disturbances, compared to

TABLE 3. Comparison of clinical presentation, EOR, and postoperative outcome between retrochiasmatic extraventricular (type 3a) and retrochiasmatic extra- and intraventricular (type 3b) craniopharyngiomas

Variable	Type 3a, n = 59	Type 3b, n = 45	p Value
Impaired vision	35 (59)	21 (47)	0.16
Raised ICP	11 (19)	27 (60)	<0.001
Behavioral disturbance	8 (14)	9 (20)	0.37
Memory disturbances	7 (12)	6 (13)	0.82
Polyphagia/polydipsia	12 (20)	11 (24)	0.61
Postop vision			
Same	27 (46)	24 (53)	0.56
Improved	27 (46)	16 (36)	
Worsened	5 (8)	5 (11)	
GTR	34 (58)	27 (60)	0.8
Postop DI	41 (69)	35 (78)	0.3
Death	2 (3)	3 (7)	NS
Hypothalamic dysfunction	6 (10)	13 (29)	0.01
Recurrence	11 (19)	16 (36)	0.05
2-, 5-, & 10-yr PFS	91%, 83%, 65%	76%, 60%, 60%	0.03

NS = not significant.
Unless otherwise indicated, values are expressed as the number of patients (%).

3% of the patients with non-RCP (p = 0.02). Among the RCPs, those with extra- and intraventricular components had a higher incidence of postoperative hypothalamic morbidities than did the extraventricular RCPs (Table 3). In patients with multicompartmental craniopharyngiomas, 50% noticed an improvement, and 17% experienced worsening of their preoperative vision postoperatively. They also experienced higher hypothalamic morbidities postoperatively (33%, p = 0.05) than did those with RCPs and non-RCPs, whereas neurological and endocrinological outcomes were comparable.

The surgery-related mortality was 4.8% and 3% in retrochiasmatic and nonretrochiasmatic tumors, respectively (p = 0.6). Between the prechiasmatic and infrachiasmatic/intrasellar craniopharyngiomas, EOR (p = 0.7), postoperative DI (p = 0.4), endocrinological outcome (p = 0.7), and recurrence (p = 0.1) were comparable. Among the RCPs, the postoperative histopathological analysis showed an adamantinomatous subtype in 89 (85.5%) and a papillary subtype in 13 patients (12.5%). In 2 patients, the tumor showed features of both subtypes. Histopathological subtypes of the non-RCPs are given in Table 2.

Recurrence and PFS

The mean follow-up duration was 58 (SD ± 35) and 58 (SD ± 31) months for RCPs and non-RCPs, respectively. During follow-up, tumor recurrence was diagnosed in 27/99 (27.3%) and 14/32 (43.7%) of the surviving patients with RCP and non-RCP, respectively (p = 0.08).

On Cox proportional hazards analysis, the EOR (HR 5.3, 95% CI 2.8–12.2; p = 0.001) and preoperative Puget grade (HR 2.8, 95% CI 1.13–6.9; p = 0.02) were the significant predictors of recurrence. Preoperative hydrocephalus

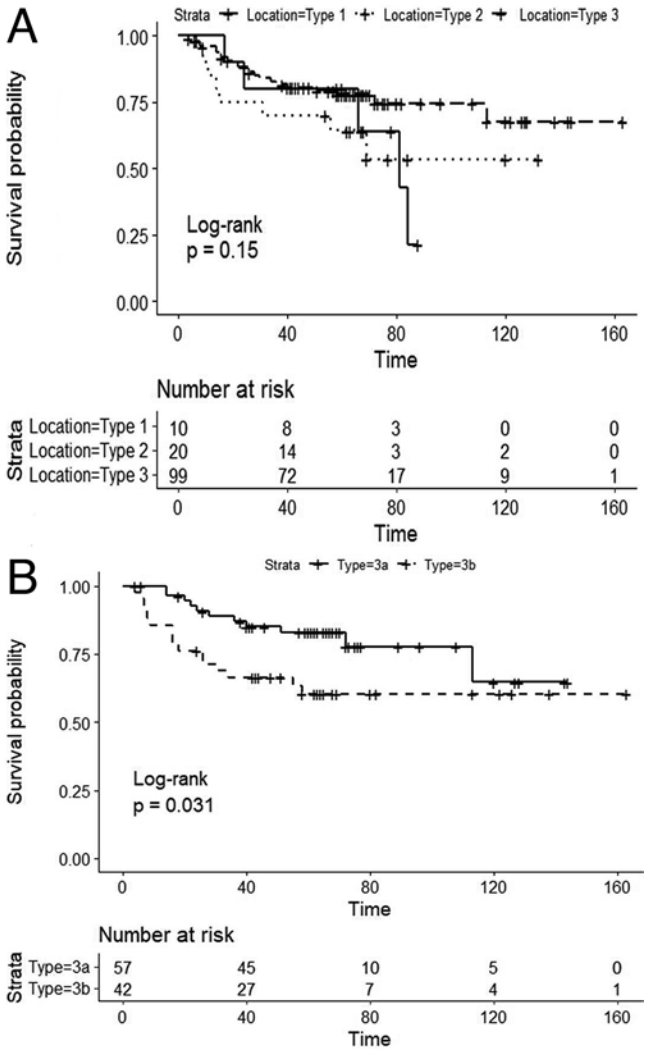

FIG. 3. KM survival curve (time is measured in months). The overall PFS after resection of prechiasmatic, infrachiasmatic, and retrochiasmatic craniopharyngiomas is comparable (panel **A**). The survival curve (panel **B**) shows a significantly shorter PFS with extra- and intraventricular RCPs (type 3b) than with extraventricular RCPs (type 3a).

(HR 0.59, 95% CI 0.25–1.3; p = 0.23); tumor size (HR 1.4, 95% CI 0.7–2.7; p = 0.2); histopathology (HR 0.8, 95% CI 0.24–2.4; p = 0.71); and preoperative hypothalamic dysfunction (HR 0.55, 95% CI 0.24–1.2; p = 0.17) were not associated with the risk of recurrence. The patients who had undergone STR had a 5.3 times higher risk of recurrence than those who underwent GTR. Similarly, the patients with grade 2 hypothalamic involvement had a 2.6 times higher risk of recurrence than those with grade 1 involvement. The location of the tumor, either retrochiasmatic (HR 0.5, 95% CI 0.14–2.2; p = 0.4) or nonretrochiasmatic (HR 1.3, 95% CI 0.3–5.5; p = 0.6), showed no association with recurrence. The KM survival analysis suggested that the RCPs with intraventricular extension were at an increased risk of recurrence than were the RCPs with extraventricular components alone (Fig. 3B).

The PFS at 2, 5, and 10 years after GTR of RCPs and non-RCPs is given in Table 2. We found no significant dif-

ference in overall PFS between infrachiasmatic, prechiasmatic, and retrochiasmatic craniopharyngiomas (Fig. 3A). Similarly, the KM survival analysis showed no significant difference in the PFS following either STR (p = 0.07) or GTR (p = 0.7) between patients with RCP and non-RCP (Fig. 4). Table 3 compares clinical presentation, EOR, and postoperative outcomes between patients with extraventricular RCP (type 3a) and those with extra- and intraventricular RCP (type 3b). Although the EOR was comparable between these two variants, type 3b had a significantly higher recurrence rate (36% vs 19%, p = 0.05) and shorter PFS (p = 0.03) than type 3a (Fig. 3). The overall PFS at 2, 5, and 10 years for the adamantinomatous variant was 92%, 72%, and 52%, and that for the papillary variant was 100%, 80%, and 80%, respectively. The PFS at 2, 5, and 10 years was comparable between RCPs and non-RCPs, either with the adamantinomatous or the papillary subtype (Table 2).

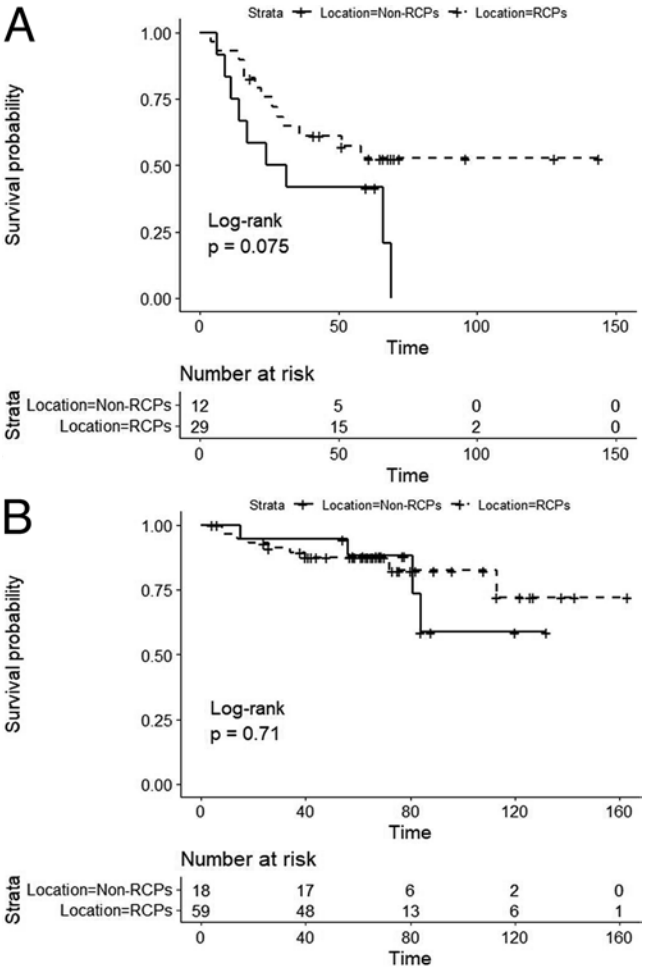

FIG. 4. KM survival curve (time is measured in months). The PFS after STR (panel **A**) and GTR (panel **B**) does not show any statistically significant difference between RCPs and non-RCPs.

Discussion

Craniopharyngiomas are generally classified according to the site of origin along the pituitary axis and their growth pattern, which dictate the tumor's location.[17,19,21] Retrochiasmatic tumors account for two-thirds of all cases. They often arise from the posterior aspect of the pituitary stalk.[19] The growth axis is predominantly directed posterior and superior toward the 3VF.[19] The optic chiasm is either in its usual position or compressed anteriorly against the tuberculum sellae. These tumors predominantly occupy the interpeduncular cistern and tend to grow behind the dorsum sellae into the posterior fossa. The prechiasmatic tumors that arise from the anterior aspect of the stalk grow superiorly between the optic nerves.[19] The optic nerves are stretched over the tumor, and the A1 segment of the anterior cerebral artery is lifted superiorly. These tumors displace the chiasm superiorly and posteriorly.

The infrachiasmatic/intrasellar tumors arise from the lower end of the stalk close to the pituitary gland, and they occupy the sella. Depending upon the patency of the diaphragma sellae, they may be wholly infradiaphragmatic or may extend to the supradiaphragmatic space and remain extraarachnoidal.[21] Intraventricular craniopharyngioma is the least common variant, accounting for 1.3% of all types. They originate at the 3VF and grow within the ventricle. The multicompartmental tumors extend beyond the suprasellar cistern into the anterior cranial fossa, parasellar region, or posterior fossa cisterns like the prepontine and cerebellopontine cisterns. Resection of these giant tumors is incredibly challenging and often requires complex surgical approaches. Another critical aspect is the tumor's relationship to the suprasellar arachnoid layer. Hu et al.[22] have classified craniopharyngiomas into three types based on the site of origin and the tumor's relation to the suprasellar arachnoid membrane. Table 4 compares our classification with other topographical classifications proposed by Hu et al.[22] and Prieto et al.[23]

Clinical and Radiological Features

The clinical presentation of patients with craniopharyngioma might vary depending on the location of the tumors.[18,22,24,25] The intrasellar tumors typically present with endocrine dysfunction without any visual disturbances. The prechiasmatic tumors present with significant unilateral vision loss and endocrine dysfunction. In contrast, patients with retrochiasmatic tumors more often present with raised ICP symptoms than do others as these lesions are likely to obstruct the CSF flow at the foramen of Monro. Visual disturbances and pituitary dysfunction may be less common in retrochiasmatic tumors than in prechiasmatic tumors. In this study, the symptoms of raised ICP, hydrocephalus, and papilledema on presentation were more common in patients with RCPs and complex multicompartmental tumors. On the contrary, visual dysfunction and optic atrophy were more frequent in patients with non-RCP. The RCPs tend to cause memory disturbances because they often distort the columns of the fornix while extending into the third ventricle. However, we found no significant difference in behavioral disturbances, memory disturbances, and endocrine dysfunction between these two groups. The patients with prechiasmatic tumors had a significantly shorter duration of symptoms than the ones with retrochiasmatic tumors in our study, because the for-

TABLE 4. Comparison between various topographical classifications of craniopharyngioma

	Our Classification	Origin	Features
QST classification[22]			
Q type	Intrasellar CPs (type 1)	Below diaphragma sellae	The suprasellar arachnoid membrane limits the superior pole
S type	Prechiasmatic CPs (type 2) & RCPs (type 3)	Along the PS (above the diaphragma sellae)	Arachnoid & 3VF are located above, & dura is below the tumor
T type	Intraventricular CPs (type 4)	At the 3VF	Occupies the 3VC
Prieto classification[23]			
Sella–suprasellar	Prechiasmatic & retrochiasmatic tumors (types 2 & 3a)	Along the PS (above the diaphragma sellae)	Suprasellar tumors w/ sellar extension; they do not displace or invade the 3VF
Suprasellar pseudointraventricular	Retrochiasmatic tumors (type 3a)	Along the PS	No sellar extension; 3VF is displaced superiorly
Secondary intraventricular	Retrochiasmatic tumors (type 3b)	Along the PS	Extra- & intraventricular components are present
Infundibulotuberal & strictly intraventricular variants	Third ventricular tumors (type 4)	At the 3VF	They occupy the 3VC; 3VF may or may not be invaded by tumor

PS = pituitary stalk; 3VC = third ventricular cavity.

mer recognized the visual disturbances early, which is the predominant symptom of prechiasmatic tumors. Retrochiasmatic tumors present relatively late and often with acute symptoms.

Despite frequent imaging evidence of grade 2 hypothalamic involvement by the retrochiasmatic tumors, we found no significant difference in preoperative symptoms of hypothalamic involvement like an altered sleep–wake cycle, weight gain, polyphagia, and polyuria between patients with RCPs and those with non-RCPs. Such findings emphasize that the tumors with radiological evidence of hypothalamic involvement need not always manifest with clinical symptoms of the same. The prechiasmatic tumors less often extend into the third ventricle as they grow superiorly between the optic nerves, although they may involve the anterior basal part of the 3VF. We also noticed a significant difference in the tumor size on MRI. The prechiasmatic tumors were relatively small compared to the retrochiasmatic tumors. The smaller size may be due to the early diagnosis of prechiasmatic tumors, given that they often present with visual disturbances, unlike retrochiasmatic tumors, which are relatively large at presentation and associated with hydrocephalus at the time of diagnosis. Sellar extension of the tumor is more frequent with prechiasmatic tumors, and retrochiasmatic tumors often remain suprasellar. Based on their intraoperative observations, Wang et al.[21] also reported that the prechiasmatic tumors had more frequent infradiaphragmatic extension than the retrochiasmatic lesions. The prechiasmatic tumors may have a site of origin relatively lower along the pituitary stalk than for the retrochiasmatic tumors.

Extent of Tumor Removal

The reported rate of GTR in craniopharyngiomas varies from 17% to 93% in the literature.[9,11,12,14,15,25] GTR was achieved in 58.6% of patients with RCP compared to 69.7% in non-RCPs in our study. The influence of the tumor's location in relation to the optic chiasm on the EOR is controversial. Van Effenterre and Boch[14] reported that the retrochiasmatic location of the tumor is a limiting factor for complete removal. They could achieve total resection in only 31% of patients with retrochiasmatic tumors compared to 80% in those with non-RCPs. They have also reported frequent invasion of the hypothalamus by the RCP as the reason for a low rate of complete removal. Several others have also contended that craniopharyngiomas involving the third ventricle have a lower GTR rate than do the other types.[22,23,25]

Steno et al.[18] have classified supradiaphragmatic craniopharyngiomas into suprasellar extraventricular, intra- and extraventricular, and intraventricular tumors based on their relation to the 3VF. All intra- and extraventricular craniopharyngiomas were essentially retrochiasmatic tumors, and suprasellar extraventricular craniopharyngiomas were predominantly prechiasmatic, except in one patient with a retrochiasmatic tumor in their study. The EOR was comparable between intra- and extraventricular craniopharyngiomas and suprasellar extraventricular craniopharyngiomas (GTR 75% vs 73%) in this study. Similarly, Caldarelli et al.[26] also did not find a significant difference in the EOR among intrasellar, prechiasmatic, and retrochiasmatic tumors. Factors like tumor location, size, hydrocephalus, histopathology, and Puget grade failed to predict the EOR in our study. Although many authors reported tumor size, infiltration of the surrounding nervous tissue, and severe hydrocephalus as the risk factors for incomplete tumor removal, others did not find such a correlation.[11,12,14,15,26–29] Despite relatively large size and frequent hypothalamic involvement on MRI at diagnosis, GTR of retrochiasmatic tumors can be achieved safely by using an appropriately selected surgical approach. The patients with complex multicompartmental tumors had the lowest rate of GTR (25%) in our study. In various studies, GTR was achieved in 30%–79.3% of patients with complex, giant craniopharyngiomas.[11,14,15,27,29,30]

Tumor Recurrence

There is a paucity of literature comparing tumor recur-

rence after the resection of RCPs and non-RCPs. The influence of tumor topography on recurrence is less often studied.[31] The reported recurrence rate in the literature is 75%–100% after STR and 0%–26% after GTR.[11,16,17,32–34] Our study found no statistically significant difference in tumor recurrence between RCPs and non-RCPs following either GTR or STR. Similarly, the PFS at 2, 5, and 10 years is comparable. The Cox regression model suggested that the EOR and preoperative Puget grade are the only factors that predicted tumor recurrence. The tumor location, size, hydrocephalus on a preoperative scan, histopathological subtype, and preoperative symptoms of hypothalamic involvement showed no association with tumor recurrence.

Tomita and Bowman[35] divided craniopharyngiomas into four types topographically: the third ventricle without sella, the third ventricle with sella, sella with suprasellar, and intrasellar type. These authors found no significant association between the tumor location and recurrence. On the contrary, Kim et al.[36] reported tumor location as the only predictor of tumor recurrence, and they found a better recurrence-free survival for suprasellar tumors than for those with intrasellar extension. Similarly, Park et al.[37] also reported supra- and subdiaphragmatic tumor location as a predictor of recurrence. However, these authors did not differentiate between retrochiasmatic and nonretrochiasmatic tumors in their studies. The high recurrence in supra- and infradiaphragmatic tumors is probably due to the frequent residual tumors in the pituitary fossa.[21,25,35–37] In such patients, the endoscopic approach alone or combined with the TCA can be helpful in complete tumor removal. A few other studies reported that the tumors involving the third ventricle are at risk for higher recurrence and have a low rate of PFS.[22,24] Our study also concludes that the extra- and intraventricular RCPs have a higher recurrence rate and lower PFS than the extraventricular RCPs despite a comparable EOR. Due to the very low rate of complete excision, the patients with multicompartmental tumors also experienced a high tumor recurrence on follow-up. De Vile et al.[11] have reported a proportionally higher recurrence rate and surgical morbidities with an increasing number of intracranial compartment involvement by craniopharyngiomas.

Neurological and Endocrinological Outcomes

Early postoperative and long-term visual outcomes are comparable between RCPs and non-RCPs. However, the patients with RCP show a significantly higher incidence of hypopituitarism, DI, and hypothalamic morbidities postoperatively. Even among the patients with RCP, those with extraventricular lesions have a lower incidence of hypothalamic morbidities than the patients who have RCPs with extra- and intraventricular components. The frequent involvement of the hypothalamus (Puget grade 2) by retrochiasmatic and complex multicompartmental craniopharyngiomas explains the higher incidence of postoperative hypothalamic morbidities. Between prechiasmatic and infrachiasmatic craniopharyngiomas, we found no significant difference in the EOR and postoperative outcomes. Giese et al.[38] reported that intrasellar tumor position and tumor extension toward the third ventricle are risk factors for long-term postoperative endocrine deterioration. Few authors have shown a higher incidence of hypothalamic dysfunction, hypopituitarism, and relatively worse functional outcome with intraventricular craniopharyngiomas.[22,24] Thus, the third ventricular involvement remains a significant risk factor for postoperative morbidities. To further emphasize this fact, Prieto et al.[23] divided the third ventricular craniopharyngiomas into infundibulotuberal or not strictly intraventricular and strictly third ventricular types, and have shown higher postoperative morbidities and recurrence with the former type.[23,31,39,40] Prieto and Pascual also reported a correlation between craniopharyngioma origin site along the pituitary-hypothalamic axis and surgical complications.[39,40] We agree with these authors that the site of origin and axis of growth of craniopharyngioma determine the tumor's relation to the hypothalamus and, subsequently, the surgical complications.

Operative Approaches and Surgical Outcomes

The results of our study should be interpreted carefully. The significant bias in our study is that the results are predominantly based on TCA. The disadvantages of TCA are brain retraction, access through corridors between the cranial nerves and critical arterial feeders, inadequate visualization of the hypothalamus, and inadequate access to the sellar part, which often result in suboptimal visual outcomes, neurological morbidities, and incomplete resection.[22,25,27,35–37] Following the reports by Frank et al.[41] and Kassam et al.[42] on expanded endonasal access to craniopharyngiomas, the endonasal endoscopic approach (EEA) is increasingly preferred as the first line of approach for craniopharyngiomas. A novel topographic classification based on the tumor's relation to the infundibulum was also proposed, which is more relevant for selecting the EEA.[42] The EEA improves EOR and visual outcomes and lowers postoperative permanent DI and panhypopituitarism.[43–48] However, studies did not find a significant difference in the hypothalamic morbidities and reported higher postoperative CSF leakage with the EEA.[44,45,47,48]

Many of the cases in our series could have been treated surgically via the EEA, and EOR and surgical outcomes might have improved. Nevertheless, a direct comparison of the EEA and TCA for craniopharyngiomas is complex due to differences in the size and anatomical features of the tumors chosen for each approach.[44,47] The studies with comparable tumor sizes found no significant differences in the EOR, postoperative DI, and panhypopituitarism.[49,50] However, they reported favorable visual outcomes with the EEA. Despite these limitations, surgical advantages like direct midline access to the tumor along its growth axis and clear visualization of the tumor–hypothalamus relation make the EEA compelling for craniopharyngiomas.[42–44,49] Future studies that consider tumor size and detailed tumor topography are required to compare the influence of EEA and TCA on the surgical outcome of craniopharyngiomas.

Conclusions

Detailed knowledge about the topography of craniopharyngioma on preoperative MRI is essential, given that it significantly influences the postoperative endocrinological and hypothalamic outcomes. The RCPs are associated

with higher endocrinological and hypothalamic morbidities than others postoperatively. However, the influence of topography on the EOR and tumor recurrence remains controversial. We found no significant difference in the EOR and tumor recurrence between the RCPs and non-RCPs. The PFS and overall mortality rate are also comparable. The RCPs with extra- and intraventricular components are associated with a higher incidence of postoperative hypothalamic morbidities, tumor recurrence, and lower PFS than the extraventricular RCPs. Similarly, complex multicompartmental craniopharyngiomas are associated with frequent tumor residues, higher postoperative morbidities, and tumor recurrence.

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Disclosures

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

Author Contributions

Conception and design: Sadhasivam, Menon, Abraham, Nair. Acquisition of data: Sadhasivam. Analysis and interpretation of data: Sadhasivam, Menon, Arora. Drafting the article: Sadhasivam, Menon, Abraham, Arora. Critically revising the article: Sadhasivam, Menon, Abraham, Nair. Reviewed submitted version of manuscript: Sadhasivam, Arora, Nair. Approved the final version of the manuscript on behalf of all authors: Sadhasivam. Statistical analysis: Sadhasivam. Administrative/technical/material support: Arora, Nair. Study supervision: Abraham, Nair.

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