The pineal gland is located in the posterior wall of the third ventricle above the quadrigeminal lamina. This autocrine gland is composed of three cellular elements: pineal parenchyma cells, glial cells, and connective tissue cells. This gland is responsible for hormone and visual function related to puberty and the sleep-wake cycle.

Pineal region tumors are rare but are more common in children than in adults, accounting for 2.7%–11% and 0.4%–1% of all tumors of the CNS, respectively, and are marked by a heterogeneity of histological type that requires multidisciplinary management. The aim of this study was to describe the clinical epidemiology of pineal region tumors and the surgical approaches used to treat them.

Outcomes and surgical approaches for pineal region tumors in children: 30 years’ experience

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OBJECTIVE Pineal region tumors account for 2.7%–11% of all CNS tumors in children. In this series, the authors present their surgical results and long-term outcomes from a pediatric pineal region tumor cohort.

METHODS A total of 151 children aged 0–18 years were treated from 1991 to 2020. Tumor markers were collected in all patients; if positive, chemotherapy was performed, and if negative, biopsy was performed, preferably endoscopically. Resection was performed when there was a residual germ cell tumor (GCT) lesion after chemotherapy.

RESULTS The distribution based on histological type, as verified by markers, biopsy, or surgery, was germinoma (33.1%), nongerminomatous GCT (NGGCT) (27.2%), pineoblastoma (22.5%), glioma (12.6%), and embryonal tumor (atypical teratoid rhabdoid tumor) (3.3%). A total of 97 patients underwent resection, and gross-total resection (GTR) was achieved in 64%; the highest GTR rate (76.6%) was found in patients with GCTs, and the lowest (30.8%) was found in those with gliomas. The supracerebellar infratentorial approach (SCITA) was the most common, performed in 53.6% of patients, followed by the occipital transtentorial approach (OTA), performed in 24.7% of patients. Lesions were biopsied in 70 patients, and the diagnostic accuracy was 91.4. The overall survival (OS) rates at 12, 24, and 60 months as stratified by histological type were 93.7%, 93.7%, and 88% for patients with germinomas; 84.5%, 63.5%, and 40.7% for patients with pineoblastomas; 89.4%, 80.8%, and 67.2% for patients with NGGCTs; 89.4%, 78.2%, and 72.6% for patients with gliomas; and 40%, 20%, and 0% for patients with embryonal tumors, respectively (p < 0001). The OS at 60 months was significantly higher in the group with GTR (69.7%) than in the group with subtotal resection (40.8%) (p = 0.04). The 5-year progression-free survival was 77% for patients with germinomas, 72.6% for patients with gliomas, 50.8% for patients with NGGCTs, and 38.9% for patients with pineoblastomas.

CONCLUSIONS The efficacy of resection varies by histological type, and complete resection is associated with higher OS rates. Endoscopic biopsy is the method of choice for patients presenting with negative tumor markers and hydrocephalus. For tumors restricted to the midline and with extension to the third ventricle, a SCITA is preferred, whereas for lesions with extension toward the fourth ventricle, an OTA is preferred.

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KEYWORDS pineal tumor; supracerebellar approach; occipital transtentorial approach; pineal biopsy; germ cell tumor; oncology

ABBREVIATIONS beta-hCG = beta human chorionic gonadotropin; ETV = endoscopic third ventriculostomy; GCT = germ cell tumor; GTR = gross-total resection; GTS = growing teratoma syndrome; NGGCT = nongerminomatous GCT; OS = overall survival; OTA = occipital transtentorial approach; PFS = progression-free survival; SCITA = supracerebellar infratentorial approach; STR = subtotal resection; VP = ventriculoperitoneal.


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them and to analyze the results of treatment in children over the last 3 decades in a Western center specializing in pediatric cancer treatment.

Methods

Patient Population

A retrospective study was conducted by analyzing the medical records of patients younger than 18 years with pineal region tumors treated at the Department of Neurosurgery of the Escola Paulista de Medicina–Universidade Federal de São Paulo and the Pediatric Oncology Institute, Brazil, from 1991 to 2020. This study was approved by the research ethics committee of the institution. The extent of resection was classified as gross-total resection (GTR), subtotal resection (STR) if the residual lesion measured ≤ 1.5 cm³, open biopsy if the residual lesion was > 1.5 cm³, and biopsy. Overall survival (OS) and progression-free survival (PFS) were analyzed. Our treatment protocol is illustrated in Fig. 1.

Surgical Approaches

Details of the surgical approaches are illustrated and described in Fig. 2. The choice of the approach was determined based on the direction of the major axis of the tumor. The supracerebellar infratentorial approach (SCITA) was used for lesions centered on the midline and extending toward the third ventricle. The occipital transtentorial approach (OTA) was used for lesions extending toward the fourth ventricle and/or with lateral extension. The interhemispheric transcallosal transchoroidal approach was used for lesions extending horizontally into the third ventricle and passing the interthalamic adhesion up to the level of the Monro foramen as well as into the mesencephalic cerebellar cistern and fourth ventricle.

Statistical Analysis

Statistical analysis was performed by plotting the Kaplan-Meier survival curves and conducting the log-rank Mantel-Cox mathematical tests when two groups were compared or the log-rank test for trend when more than two groups were compared. The qualitative variables were analyzed by contingency tests, including the chi-square and Fisher’s exact tests, depending on the sample size and the normality of the distribution for each set of samples. The Kruskal-Wallis test was used for multiple comparisons between medians of nonparametric samples. A multivariate analysis was conducted with multiple logistic regression models, where we selected age and sex, along with the variables of univariate analysis that were statistically significant (p < 0.05). An \( \alpha < 0.05 \) was considered statistically significant. Data analysis and graph creation were performed using GraphPad Prism version 8.0.1 software.

Results

Patient and Tumor Characteristics

The prevalence of pineal region tumors in our series was 7.33% (151/2061) among all CNS tumors from 1991 to 2020. The overall sex ratio was 3 males (n = 111) to 1 female (n = 40), and this difference was more pronounced among patients with germ cell tumors (GCTs) (15:1). The median ages were 13 years (range 6–18 years)
FIG. 2. Illustrations showing the different approaches we used. A–C: SCIA. This approach is performed with the patient in a sitting position, and somatosensory and motor evoked potentials are monitored. A proclivity maneuver is performed on the table to keep the cerebellar tentorium parallel to the ground. A rectilinear incision is made at the midline, and a broad suboccipital craniotomy of the superior nuchal line exposes the lower portion of the transverse sinus bilaterally to the foramen magnum, and the posterior arch of C1 is removed to expose the cisterna magna for CSF drainage and achieve cerebellar relaxation. The cerebellar tentorial surface is carefully dissected under microscopy to release the arachnoid adhesions, coagulation occurs in the bridged veins and the cerebellar precentral vein, and the arachnoid mater is microdissected to establish access to the pineal gland region. After the lesion is resected, the region is inspected with a neuroendoscope using 0° and 30° optics. The patient is kept in a semisitting position for a minimum period of 48 hours to avoid venous bleeding in the surgical bed. D–F: OTA. The access is established with the patient in a three-quarters prone position with the access side oriented inferiorly to allow gravitational retraction of the occipital lobe and expansion of the occipital interhemispheric pathway. FIG. 2. (continued) →
In this approach, the deep venous complex is superior and lateral to the tumor. To broaden the field of view, we can open the cerebellar tentorium next to the straight sinus. In cases in which the tumor extends to the body of the third ventricle, the splenium of the corpus callosum can be opened. G–L: Interhemispheric transcallocsal transchoroidal approach. The access is established with the patient in the supine position, neutral cephalic. A transverse incision is made on the coronal suture, and a paramedian frontoparietal craniotomy is performed centered in the coronal suture. Frontal interhemispheric microdissection is performed. A callototomy is performed 2 cm behind the genu of the corpus callosum between the pericallosal arteries. The choroidal fissure is dissected to open the upper membrane of the choroidal mesh. The internal cerebral veins, medial branches of the posterior choroidal artery, and lower membrane of the choroidal mesh are exposed and separated. Coagulation occurs in the choroid plexus, and the posterior part of the third ventricle is exposed. The septal vein can be sacrificed if the surgical region needs to be extended toward the foramen of Monro to allow opening of the choroidal fissure through the taenia fornices; however, the thalamostriate veins, internal cerebral veins, basal vein of Rosenthal, and the large vein of Galen must be preserved. The precentral cerebellar vein undergoes routine coagulation. J–L: Neuroendoscopic biopsy. The patient is placed in the dorsal decubitus position with the head elevated to 30° in the neutral cephalic position. Trepanation was performed 2.5 cm from the midline at the midpoint between the coronal suture and the scalp line. An Aesculap rigid neuroendoscope with a previous rotation of 180°, with a working channel at 6 o’clock and a 0° optic, was introduced into one of the lateral ventricles under continuous irrigation with 0.9% saline solution heated to 37°C (J). For clear subependymal lesions, we initially opened the ependyma for subsequent biopsy, and after meticulous revision to achieve hemostasis, an ETV was performed, with the aid of a 4-Fr Fogarty probe, to open the tuber cinereum and the Liliequist membrane (K). The ventricular ependyma was carefully inspected to identify any possible metastasis, and hemostasis was achieved through irrigation with heated saline solution. When the ventricular cavity is small, we use neuronavigation coupled to the endoscope to access the ventricle and choose the best trajectory (L). A single burr hole was created between the two ideal locations to allow both biopsy and ETV. © Marcos Devanir Silva da Costa, published with permission.

among patients with germinomas, 9 years (range 0–16 years) for those with nongerminomatous GCTs (NG-GCTs), 5.5 years (range 0–17 years) for those with pineoblastomas, 11 years (range 0–18 years) for those with gliomas, and 4 months (range 0–1 year) for those with embryonal tumors (Table 1).

The distribution stratified by histological type was as follows: 33.1% (n = 50) were pure germinomas, 27.2% (n = 41) were NG-GCTs (which included choriocarcinomas, endodermal sinus tumors, mature and immature teratomas, and mixed tumors), 22.5% (n = 34) were pineoblastomas, 12.6% (n = 19) were gliomas, 3.3% (n = 5) were embryonal tumors, and 1.32% (n = 2) were miscellaneous tumors, which included a cavernous hemangioma in one patient and a pineal tumor of intermediate cells in another patient. Two patients with high levels of alpha-fetoprotein and beta human chorionic gonadotropin (beta-hCG) whose tumors disappeared following chemotherapy with the tumor markers returning to normal experienced another tumor, a mature teratoma, that appeared in the same region, which is a characteristic of growing teratoma syndrome (GTS) (Fig. 3).

The most common clinical manifestations were signs and symptoms of increased intracranial hypertension (headache, vomiting, diplopia and/or an altered level of consciousness) and were observed in 79% (120/151) of the patients. Cranial nerve disorder was observed in 45% of patients (68/151); cerebellar syndrome, such as gait ataxia, loss of balance and dizziness, in 21% (32/151); hormonal disorder, such as precocious puberty and diabetes insipidus, in 20% (30/151); Parinaud’s syndrome in 7.3% (11/151); and motor deficits in 7.3% of patients (11/151).

Twenty percent of the pure germinomas were beta-hCG positive (serum and CSF), but this positive marker was not significantly related to a worse prognosis (OR 0.9, 95% CI 0.1–8.8; p = 0.94) An alpha-fetoprotein level less than or greater than 1000 ng/ml in patients with an NG-GCT was also not significantly associated with a worse prognosis (OR 0.53, 95% CI 0.11–2.39; p = 0.41).

Surgical Treatment and Outcome

In this series of 151 patients with pineal region tumors, 70 patients underwent biopsy, 65 patients underwent resection, and 16 patients underwent chemotherapy and/or radiotherapy based on tumor markers. After biopsy, 32 patients also needed tumor resection, resulting in a total of 97 patients (64%), and lesions were completely resected in the first intervention in 64% (62/97) of patients.

Regarding the surgical approach, SCITA was used in 53.6% of patients (52/97), OTA in 24.7% (24/97), interhemispheric transcallocsal transchoroidal approach in 10.3% (10/97), transcortical transchoroidal approach in 10.3% (10/97), and transventricular endoscopic approach in 1% of patients (1/97).

Patients who underwent a SCITA had the best results, with GTR being achieved in 61.5%, followed by those who received a transcortical or transcallocsal approach (GTR in 60%) and OTA (GTR in 50%) (Fig. 4A).

GTR was achieved in a higher percentage of patients with GCTs (including pure germinomas, teratomas, and

| TABLE 1. Distribution of patient sex and age according to histological tumor type |
|---------------------------------|---------|---------|
|                                | Sex, n (%) | Age, yrs |
|                                | Male | Female | Mean | Median | Total |
| Embryonal tumor (ATRT)         | 2 (40) | 3 (60) | 0.4  | 0.25   | 5     |
| Pineoblastoma                  | 13 (38.2) | 21 (61.8) | 6.6  | 5.5     | 34    |
| NGGCT                          | 38 (92.7) | 3 (7.3)  | 9.5  | 9       | 41    |
| Glioma                         | 11 (57.9) | 8 (42.1) | 11.68 | 11      | 19    |
| Germinoma                      | 47 (94) | 3 (6)   | 13.2  | 13      | 50    |

ATRT = atypical teratoid rhabdoid tumor.
NGGCTs) at 76.6% (36/47), followed by pineoblastomas at 60.7% (17/28) and gliomas at 30.8% (4/13). These differences were statistically significant ($p = 0.008$) (Fig. 4B). Within GCT groups, GTR was achieved in 68.4% of patients with pure germinomas, 83.6% of those with malignant NGGCTs (choriocarcinoma, yolk sac tumor, and embryonal carcinoma), 68.7% of those with mixed tumors, and 60% of those with mature teratomas.

Most of the surgical complications were transient, and the main complications were changes in extrinsic ocular motor function, especially paresis of the vertical conjugated gaze, which was observed in 13 patients. CSF fistulas were observed in 2 patients. Parinaud’s syndrome in the preoperative or postoperative period disappeared within 2 months following the operation in all patients.

One patient died of hypovolemic shock due to venous rupture distant from the approach area during surgery for a large teratoma diagnosed in utero. Although the SCITA is commonly performed with the patient in the sitting position, none of the patients developed symptomatic air embolism.

The study was performed over 3 decades, and the proportion of patients in whom total resection was achieved increased in the last decade (68.1%) with respect to the 1st (64.7%) and 2nd (61.7%) decades, although the difference was not statistically significant ($p = 0.83$) (Fig. 4C).

Tumor biopsy was performed in 70 patients (46.4%), of whom 59 patients (84.3%) underwent endoscopy, 8 (11.4%) underwent stereotaxy, and 3 (4.3%) underwent biopsy via an opening into the suprasellar lesion (synchronous lesions). A neoplasm was not found on biopsy in 2 cases, and the results were inconclusive in 4 cases. The sensitivity of the biopsy was 91.4%.

A ventriculoperitoneal (VP) shunt was placed in 92 patients (61%), with a success rate of 72.5% at 12 months and the highest rate of shunt dependence in the patients with pineoblastomas (80%, $p = 0.0002$). Thirteen patients had surgical complications. There were 5 cases of ventriculitis, 9 cases of intracranial hemorrhage, and 1 case of slit ventricle. Endoscopic third ventriculostomy (ETV) was performed in 60 patients (39.7%), with a success rate of 60% at 12 months, and only 1 patient had a surgical wound infection. There was no significant difference between VP shunt treatment and ETV in terms of the success rate at 12 months ($p = 0.11$). However, ETV was associated with lower complication rates than VP shunting (1.69% vs 14.13%; OR 0.1, 95% CI 0.009–0.59; $p = 0.009$).

Long-Term Survival

The OS rates at 12, 24, and 60 months as stratified by histological type were 93.7%, 93.7%, and 88% for patients with germinomas; 84.5%, 63.5%, and 40.7% for patients with pineoblastomas; 89.4%, 80.8%, and 67.2% for patients with NGGCTs; 89.4%, 78.2%, and 72.6% for patients with gliomas; and 40%, 20%, and 0% for patients with embryonal tumors, respectively ($p < 0.0001$) (Fig. 4C).
When patients with pineoblastomas were stratified by age, the 60-month survival rate was 46% for patients older than 3 years and only 25% for those younger than 3 years.

When separated by decades of treatment, the 2nd decade (2001–2010) had a lower OS rate than the 1st (1991–2000) and 3rd (2011–2020) decades (Fig. 5B).

OS was significantly higher in the group with GTR than in the group with STR (69.7% vs 40.8%, p = 0.04) (Fig. 5C). However, the PFS rate at 5 years was 56% for the group with GTR versus 37.6% for the group with STR, and the difference was not significant (p = 0.15).

The 5-year PFS rate was 77% for patients with germi-

nomas, 72.6% for those with gliomas, 50.8% for those with NGGCTs, and 38.9% for those with pineoblastomas.

**Multivariate Analysis**

The multivariate analysis of OS at 2 years included the following variables: age, female sex, extent of resection, treatment after 2010, and histological types (pure germinoma, NGGCT, glioma, and pineoblastoma). The results indicated that patients with histological type pure germinomas had a better chance of survival at 2 years. The OR was 13.25 (95% CI 1.004–218.5), and the generated model was accurate, with an area under the curve of 0.71 (95% CI 0.58–0.84) (p = 0.0027).

**Discussion**

Tumors of the pineal region account for 2.7%–11% of all CNS tumors in children. The highest incidences of these tumors are described in cohorts from Eastern countries, with values 5 times higher than those in Western cohorts. For a long time, it was believed that the incidence of pineal GCTs was higher in Asian countries. However, in 2012,
McCarthy et al. published their results in a population-based epidemiological study comparing the prevalences between the United States and Japan. In this study, they demonstrated that there was no significant difference in the incidence of pineal GCTs between the two countries. We observed a high prevalence of pineal tumors, 7.33%, compared with other Western countries. We believe that such prevalence, as well as the progressive increase in cases, is justified because we are a team of experts providing multidisciplinary management and therefore receive complex cases, not only pineal region tumors, from several other Brazilian states. The incidence by sex was similar to that of the Eastern series, with a ratio of 3 males to 1 female.

The heterogeneity of histological tumor types in this location is justified by the variety of cell types that can be found in this region. According to the Surveillance, Epidemiology, and End Results (SEER) Program, germ cell and pineal parenchymal tumors account for 89% of all tumors in this region. A French group reported the following distribution: 27% GCTs, 27% pineal parenchymal tumors, 17% gliomas, 8% papillary tumors of the pineal region, 7% pineal cysts, and 1% embryonal tumors. In our case series, we observed the following distribution: 60.3% GCTs, 22.5% pineal parenchymal tumors, and 12.6% gliomas. Our distribution is in line with the pediatric population, which explains the low incidence of pineal gliomas. Higher rates of gliomas have been observed by authors studying tumors of the pineal region and account for gliomas of the pineal, midbrain, and posterior portion of the thalamus. Tomita et al. found 22 (27.5%) benign astrocytomas among 80 pediatric patients with tumors in the pineal region.

The clinical presentation of pineal tumors can be divided into three groups: intracranial hypertension, focal neurological deficits, and hormonal disorders. The most common clinical manifestation is intracranial hypertension secondary to obstructive hydrocephalus, which was present in 80% of the patients in our series whose main complaint was headache.

Another important manifestation is Parinaud’s syndrome, presenting as paresis of the vertical conjugate gaze, mydriasis, and divergent strabismus due to compression of the dorsal midbrain, found in 7.2% of our patients. Hormonal dysfunction presents with diabetes insipidus or early puberty. The first can occur due to the presence of bifocal lesions, when there is a lesion in the pituitary stem, or by microscopic dissemination of the lesion on the floor of the third ventricle, even in patients with lesions apparently restricted to the pineal region. Early puberty occurs due to the production of beta-hCG, which is more frequently observed in patients with NGGCTs, especially choriocarcinomas. Hormonal disorders were detected in 20% of our patients.

The use of neuroendoscopy in the management of lesions of the pineal region has four objectives: resolution of hydrocephalus, tumor biopsy, CSF sampling for oncotic cytology and tumor markers, and the possibility of identifying small foci of tumor spread on the floor of the third ventricle that cannot be identified on imaging. A histological diagnosis through endoscopic biopsy has high sensitivity, ranging from 75% to 94%, and in our case series, we achieved 91.4% congruence between the biopsy results and the postoperative anatomopathological findings.

Several techniques have been described in neuroendoscopy for the management of lesions in the pineal region, and the best choice depends mainly on the experience of the neurosurgeon, the size of the lateral and third ventricles, the size of the intermediate mass and its relationship with the lesion, and, if present, anterior or posterior extension. Another point of discussion is the procedure that should be performed first; many authors recommend performing ETV before the biopsy with the goal of prioritizing the resolution of hydrocephalus and fearing that potential bleeding from the biopsy would prevent the performance of the ETV. In our series, we initially performed the biopsy and then opened the tuber cinereum and Liliequist membrane. We consider it safer to perform the biopsy before ETV because any bleeding that occurs due to removal of the fragment can possibly be stopped before opening the floor of the third ventricle, thus minimizing the risk of extraventricular hemorrhage. In the literature, less than 2% of patients have been reported to die as a result of surgery, and the rate of GTR varies from 40% to 80%. In our cohort, only 1 patient died due to surgery.

Authors have debated the best approach, either the SCITA or OTA, for pineal region tumors. The SCITA is ideal for lesions located in the midline, growing toward the third ventricle, inferior to the vein of Galen complex, and below the plane of the tentorium, offering excellent expo-
sure of the region, especially with the patient in the sitting position; however, for tumors with lateral extension and extending into the fourth ventricle, this pathway is less advantageous. In our series, 52 patients underwent the SCITA, and there were no cases of symptomatic air embolism, allowing GTR at the first approach in 67.3% of patients. We should note that most pineal tumors are germinomas and that after tumor confirmation by the freezing test, the need for GTR is unnecessary; thus, we proceeded to perform a less aggressive resection. Shabo et al. studied 58 patients with pineal germinomas from the SIOP CNS GCT 96 trial who underwent resection mainly via SCITA. Complete resection of the lesion was obtained in 29.8% of cases, with 43.2% experiencing complications in the postoperative period.

The OTA is a great alternative for large lesions that extend to the dorsolateral portion of the brainstem, fourth ventricle, cisterna ambiens, inferior colliculus, and anterior portion of the cerebellar vermis but is less favorable for lesions extending to the anterior portion of the third ventricle. Cinalli et al. proposed that the Herophilus-Galen line can be a predictor of the extent of resection. However, large tumors in the cisterns and ventricular cavities undergo an intense brain shift, casting doubt on the functionality of these measures. GTR was achieved in 74% of these tumors by using this approach, while Tomita et al. reported that GTR was achieved in 68.75% of cases in a series of 80 tumors of the pineal region. We used this approach in 34 patients, but for 10 patients, we had to extend access to the splenium of the corpus callosum to expand the resection, converting it to Dandy's approach. In the 24 patients who underwent the pure OTA, the GTR rate was 50%.

The transcallosal transchoroidal or interforniceal interhemispheric approach offers the shortest path to lesions extending into the third ventricle without sacrificing any of the cortical veins, since it is estimated that in 90% of individuals, there is no venous drainage 5 cm posterior to the coronal suture. The approach also allows good resection of lesions that extend to the posterior fossa and are anterior to the fourth ventricle. However, in this pathway, there may be excessive manipulation of the deep veins and brain tissue. The interforniceal transcallosal approach was used in 10 patients and was chosen when the lesion extended anteriorly beyond the interthalamic adhesion and in very young children in whom the sitting position was difficult to attain. Jia et al., using the interforniceal transcallosal approach in 150 patients with pineal region tumors, found that among children, 62.6% of patients would develop transient memory deficits, and 9.3% definitively developed Parinaud's syndrome. Winkler et al. reported language changes in 33% of patients undergoing this approach. We believe that although the transcallosal transchoroidal approach allows the same access as the interfornical transcallosal approach, it does not induce memory disorders since neither fornix is manipulated. Xing et al. used this approach in 15 pediatric cases and achieved 100% complete resection with no memory alterations.

In our series, the most common approach was the SCITA, but compared with the other approaches, there was no significant difference in the total resection rate or the morbidity associated with the procedure. Thus, there was no superiority of one approach over the other, and the surgeon must have knowledge of all the approaches to determine the best one to use for a given case to obtain greater exposure of the lesion.

GTR was observed in 64% of patients across all histological types. FIG. 6. Resection of pineal region tumor via a SCITA with the aid of neuroendoscopy inspection. A: Postgadolinium T1-weighted sagittal MR image showing a pineal region tumor. B: Microscopic view of the tentorial surface of the cerebellum. C: Exposure of the tumor from the microscopic phase. D: Final view of the microsurgery resection. E: Initial view of the endoscope. F: Inspection of the endoscope revealing tumor in the bottom of the field. G: Final view of the endoscope with complete resection of the tumor. H: Postoperative sagittal MR image showing complete resection of the tumor. Figure is available in color online only.
underwent a major revolution with significant improvement over time, in our analysis of the last 30 years, we observed an evolution in the surgical results in the last decade, in which a greater extent of resection and lower patient morbidity were achieved. Our results in the 2nd decade of treatment were not satisfactory. However, during this decade, we participated in the Third International CNS Germ Cell Tumor Study, which revealed that intensive chemotherapy regimens, used in particular cases, were less effective than irradiation-containing regimens.28

The role of surgery in tumors of the pineal region depends on the histological type.29 In germinomas, surgery plays a key role in obtaining material for biopsy; however, the gold standard for treatment currently consists of a combination of chemotherapy and radiotherapy.30 Radical surgery is the main treatment for teratomas and GTS, when the lesion recurs after complete disappearance on imaging and tumor markers are negative.29 In our series, 2 patients presented with GTS, and the lesions were completely removed, one by using the SCITA and the other by using the OTA. Tarinkulu and Özek reported low morbidity following the resection of 10 mature teratomas via the OTA.31

In NGGCTs, surgery plays a key role in the treatment of residual lesions after chemotherapy, since residual lesions are the worst prognostic factor for these tumors.29,30 In addition, we performed radiotherapy after complete disappearance of tumor markers. Tumors of the pineal parenchyma require radical resection.29 In gliomas, it is very difficult to achieve complete resection, probably due to their invasive nature, so the goal is instead maximal safe resection.32

Our study showed a better overall outcome in patients with GTR. However, when we analyzed resection by histological type, the GTR rate in patients with gliomas was 30.8%, possibly due to their intrinsic and invasive nature. Pineal gliomas are difficult to resect due to adhesions to the midbrain and thalamus; the 5-year OS rate was 72.6%, and these tumors are not subjected to radiotherapy. Patients with germinomas had the best outcomes, with an 88% OS rate; among patients with NGGCTs, the OS rate was 67.2%. Tumors that generally affect younger age groups, such as embryonal tumors (particularly atypical teratoid rhabdoid tumors) (mean age 4 months) and pineoblastomas (mean age 5 years), are still a major challenge because the 5-year OS rates of these patients were 0% and 40.7%, respectively, similar to the results found by Dhall et al. and Li et al.33,34 These authors also showed that patients younger than 3 years had a worse prognosis, and the same was also observed in our patients, where only 25% of pineoblastoma patients younger than 3 years survived longer than 60 months, and among those older than 3 years, the survival rate was 46%.

Limitations
One limitation of the study is the lack of details in adjuvant and neoadjuvant chemotherapy and radiotherapy protocols. In addition, the senior author may have been biased by his preferences when choosing the approaches, which is difficult to depict in statistical analyses. However, the senior author tried to stratify the patients by the direction of the tumor’s extension to guide his decision when choosing between the surgical approaches.

Conclusions
Pineal gland tumors are marked by heterogeneity of histological type and require a multidisciplinary approach. For tumors with negative markers, it is essential to obtain samples of the lesion, and, in this context, neuroendoscopy is the method of choice because it is a safe and effective technique for histological diagnosis and allows the treatment of hydrocephalus. Surgery is challenging due to the complex anatomy of the region, and its effectiveness varies according to the histological type. The SCITA is preferred for tumors restricted to the midline and extending into the third ventricle, whereas the OTA is preferred for lesions with lateral extension and into the fourth ventricle.

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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**


**Supplemental Information**

Previous Presentations

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