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Pineal Region Tumors

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1. Introduction

The pineal region can be affected by different types of lesions, ranging from benign masses (e.g. pineal cysts) to highly malignant tumors. These neoplasms are typical of the pediatric age, while they are rarer in adults. Due to the extreme heterogeneity of the cell types of the pineal gland and its surrounding structures, these tumors include several entities, namely germ cell tumors (GCTs), which are the most common (about 70% of the pineal region tumors, PRTs), primary parenchymal tumors (PPTs) arising from the pineal parenchyma (from pineocytoma to highly malignant pineoblastoma) and other tumors, including gliomas, metastases, and tumoral invasion of the gland by adjacent tumors (gliomas, meningiomas and others). GCTs, ependymomas and pineal cell tumors typically give “drop metastasis” through the cerebrospinal fluid (CSF). PRTs have no pathognomonic radiological features; CSF and serum markers can be helpful in this challenging differential diagnosis, which leads to different therapeutical approaches.

2. Epidemiology

Pineal masses, including benign pineal cysts, are common (up to 10% as incidental magnetic resonance imaging, MRI, finding) (Gaillard & Jones, 2010), while autoptic studies showed a prevalence of 20-40% (Hasegawa et al., 1987); the benign pineal cyst, which is beyond the goal of this chapter, is largely the most frequent pineal mass. Conversely, PRTs are relatively rare, accounting for 3-8% of intracranial pediatric tumors and <1% in adults (Regis et al., 1996). GCTs are the most common tumors of this region (70%), including germinomas (50%) and teratomas (15%) (Tab. 1); they account for 0.3-3.4% of brain tumors in western population, while in Asian population they are up to eight times more common; they are also more common in patients with Down syndrome; PPTs account for another 15% (Gaillard et al., 2010; Smirniotopopoulos et al., 1992).

3. Physiopathology and clinical features

The pineocyte is the main cell of the pineal gland; it produces melatonin, a hormone involved in wake/sleep and seasonal functions. The release of melatonin is triggered by sympathetic

fibers originating from the retina, that reach the gland through the hypothalamus. Pineal gland is also involved in luteinizing (LH) and follicular stimulating hormone (FSH) production control. The blood-brain barrier is absent in the pineal region. Clinical symptoms associated with PRTs are non-specific (headache and seizures), endocrine disturbances and mass-related manifestations. The most common endocrine disturbance is precocious puberty; hypogonadism and diabetes insipidus are rarer. The origin of the precocious puberty is not clear, but it is probably due to the suppression of the antigonadotrophic effect of the gland itself or of the median eminence, or to the ectopic production of LH and FSH (Gaillard & Jones, 2010; Smirniotopoulos et al., 1992). The mass-related disturbances are hydrocephalus, dorsal midbrain syndrome and direct compression of the surrounding structures. Obstructive hydrocephalus is the result of silvian aqueduct compression or distortion, with increased intracranial pressure signs, such as headache, vomiting and nausea. The dorsal midbrain syndrome, also known as Parinaud Syndrome, is due to the direct compression of the nuclei of the quadrigeminal plate; this syndrome consists of vertical upward gaze, convergence and accommodation palsy (Pearce, 2005; Jacobs & Galetta, 2007). Direct midbrain compression can give cerebellar, motor and sensory disturbances (Klein & Rubinstein, 1989).

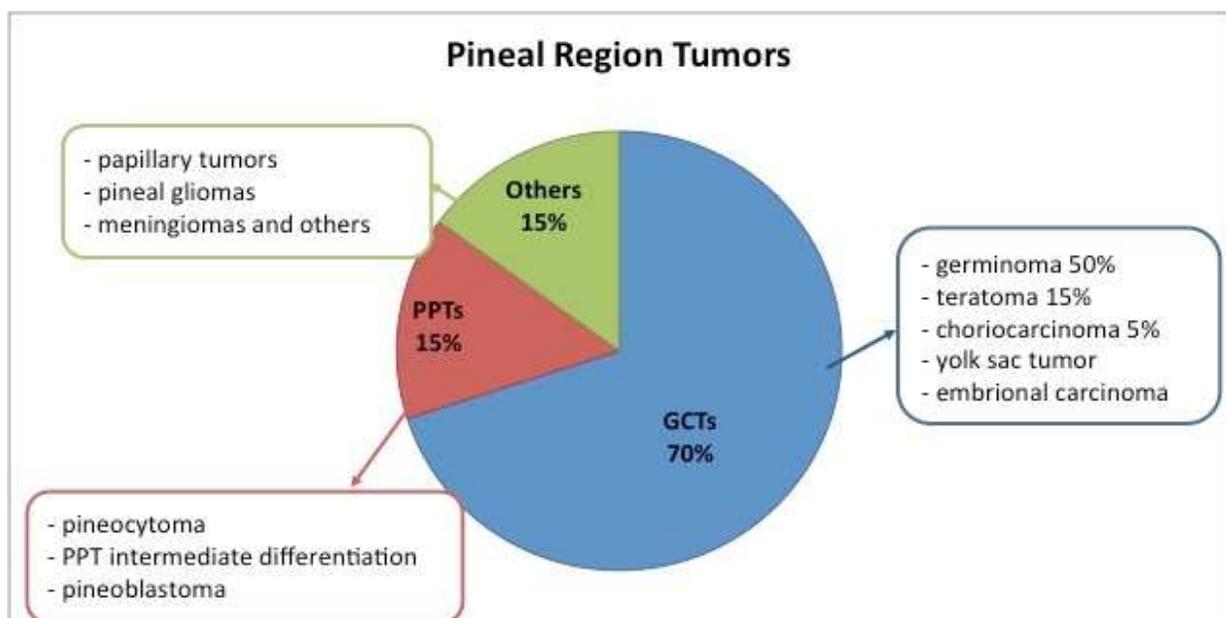


Table 1. Prevalence of various subtypes of PRTs

4. Pathology

Tumors of the pineal region can be divided into GCTs, including germinoma and non-germinomatous germ cell tumors (NGGCTs), PPTs, and others, such as papillary tumor of the pineal region, pineal gliomas, metastasis, and tumors from invasion of the gland by adjacent tumors.

4.1 Germ cell tumors

GCTs can be located both in the pineal region and in the suprasellar region; 13% of GCTs are bifocal and are called "synchronous GCTs" (Sugiyama et al., 1992). Pineal GCTs are more common in males, while the suprasellar ones appear more frequently in females. All of the

GCTs, excluding mature teratomas, are highly malignant and potentially metastatic. Germinoma (accounting for 50% of all pineal tumors) is an extra-gonadal seminoma, having a peak of incidence in the second decade of life (Villano et al., 2008). Alpha-fetoprotein (AFP) and beta-human chorionic gonadotrophin (β -hCG) are not typically increased, even if an elevation of β -hCG can occur (Horowitz & Hall, 1991). Germinomas have a better prognosis than NGGCTs, being generally radiation therapy-responding (Villano et al., 2008; Shibamoto et al., 2001) with a high rate of long term cure. NGGCTs include teratoma (15% of pineal tumors), choriocarcinoma (5% of pineal tumors), yolk sac tumor and embryonal carcinoma (both rarer). They arise from a totipotential germ cell. Teratomas of the pineal region are more common in males and in childhood/early adulthood, and are classified as extra-axial teratomas. They can have different grades of differentiation, from well differentiated (mature) to indifferentiated and aggressive (immature) teratomas. AFP is only occasionally elevated in patients affected by these tumors. Choriocarcinomas are classically associated with the elevation of CSF and plasmatic β -hCG concentration; they are frequently metastatic and prone to hemorrhage. Yolk sac tumor, also known as endodermal sinus tumor, is usually malignant and is often (up to 50%) associated with other GCTs in the context of a mixed GCT (Smirniotopoulos et al., 1992). CSF β -hCG and AFP are typically increased. Embryonal carcinoma is an aggressive and metastasis-prone tumor with an infrequent elevation of β -hCG and AFP. It is often the most aggressive component of a mixed GCT (Smirniotopoulos et al., 1992).

4.2 Pineal parenchymal tumors

As stated above, PPTs account for 15% of the PRTs. They all derive from pineocytes and, accordingly with the World Health Organization (WHO) (Louis et al., 2007), can be divided into three groups: pineocytoma, pineal tumor of intermediate differentiation and pineoblastoma. Pineocytoma is a WHO grade I tumor, which affects young adults without significant gender difference. It is usually a solid mass, even if it can show hemorrhagic or cystic appearance; it is a highly differentiated, well circumscribed tumor, with a low growth rate and rarely gives metastases. The pineal tumor of intermediate differentiation, as its name suggests, has a biological behavior and a grade of differentiation which is intermediate between pineocytoma and pineoblastoma (WHO grade II/III). Pineoblastoma is a highly malignant tumor (WHO grade IV) which affects young patients without significant gender difference. It is biologically close to medulloblastoma and primitive neuroectodermal tumors and can be associated with retinoblastoma. It is prone to metastasize and to give obstructive hydrocephalus.

4.3 Other tumors

Papillary tumor of the pineal region is a rare and relatively new entity, having been introduced in the latest (2007) WHO Classification of Tumors of the Nervous System (Louis et al., 2007). It arises from ependimocytes of the subcommissural organ located in the lining of the posterior commissure (Chang et al., 2008; Júnior et al., 2011), and is hardly distinguishable from other tumors. Pineal gliomas (fibrillar, pilocytic, anaplastic astrocytoma, glioblastoma, oligodendroglioma) and ependymomas of the pineal gland have been reported; they are more likely originating from adjacent structures rather than from the pineal gland. Epidermoid and dermoid cysts account for 3-4% of the intracranial tumors; 1% of them occur in the pineal region (Konovalov et al., 1999); dermoid cysts are much more

common than epidermoid cysts. They are congenital inclusion cysts more than properly tumors, even if their neoplastic transformation has been rarely observed. The absence of the blood-brain barrier in this region makes metastases relatively common in this area. Up to 5% of patient with spread metastatic disease show metastases to the pineal gland; the most common arise from lung, breast, kidney, cervical, oesophageal, gastric and colonic primary tumors (Lassman et al., 2006). Any kind of tumors, such as meningiomas, choroid plexus papillomas, tectal gliomas, lymphomas and lipomas, originating from nearby structures, can involve the pineal region (Gaillard & Jones, 2010).

5. Neuroradiology

The variability of the shape of the pineal gland (Sener, 1995), the possible presence of calcification in a normal pineal gland context (about 10% of children between 11 and 14 years) (Kilgore et al., 1986) and the high prevalence of pineal cysts make it hard to diagnose a pineal gland tumor; in many cases it is not possible to achieve a correct diagnosis only by means of neuroradiological features. Pineal cysts is a non neoplastic mass which has to be distinguished from pineal tumors; it appears as a well circumscribed, CSF density/intensity lesions; their rim can show some calcifications and have some contrast enhancement. In atypical cases, a nodular enhancement can occur, making the differential diagnosis between a pineal cyst and a pineal tumor impossible (Gaillard & Jones, 2010). Germinomas are isodense or slightly hyperdense masses on computed tomography (CT); they are isointense to the brain in T1- and T2-weighted images on MRI. They can engulf calcifications and they are brightly enhancing after contrast in both CT and MRI. Up to half of them can have cystic components. The simultaneous involvement of the pineal and pituitary gland ("synchronous GCT") is a pathognomonic radiological feature of germinomas. NGGCTs have highly variable radiological findings, but some data can help narrowing the differential diagnosis: in general the presence of a cystic component is more common than in germinomas; fat and calcifications are more common in teratomas; hemorrhagic findings are more frequent in choriocarcinomas, appearing as blooming signal in T2-weighted images on MRI. PPTs differential diagnosis is problematic. Pineocytoma is a more defined and more homogeneous lesion than pineoblastoma, the latter being usually bigger, often showing local adjacent structures invasion and CSF metastases at presentation. They enhance on postcontrast images; calcifications, if present, are peripheral rather than engulfed, like it happens in germinomas. Papillary tumors of the pineal region do not have specific features: they have a high T1 signal on MRI, like other tumors; they show a moderate contrast enhancement and tend to content cystic areas. Pineal gliomas do not have specific radiological appearances, while metastases show frequently a coexistent leptomeningeal enhancement.

6. Treatment and prognosis

6.1 General principles

More than 50% of patients with a PRT have some degree of hydrocephalus due to compression of the cerebral aqueduct and, if symptomatic, control of CSF flow is a necessary initial step (Kononov & Pitskhelauri, 2003; Yamini et al, 2004). The optimal surgical strategy for treating ventricular enlargement in these patients is endoscopic third

ventriculostomy (ETV) even because, in selected cases and in experienced hands, this technique may be coupled with a biopsy of the tumor (Bruce & Ogden, 2004). Nevertheless, placement of an external ventricular drain (EVD), with a careful post-operative weaning, is still a reasonable procedure in those patients in whom a gross-total resection of the pineal neoplasm with restoration of CSF flow is highly probable, especially if mildly symptomatic. Due to a relatively high rate of infection, metastasis, malfunctioning and symptomatic overshunting, ventriculo-peritoneal shunt (VP-shunt) should be considered after an ETV failure or when the tumor involves the floor of the third ventricle to such a degree as to make ETV unsafe or unlikely to remain functional (Moise et al, 2011). Despite modern neuroradiological techniques, tumor histology cannot be reliably predicted based on radiographic features alone. Only high CSF and/or serum levels of malignant germ cell markers (AFP and/or β -hCG) make surgery and biopsy unnecessary (these patients should be treated with radio and chemotherapy) (Moise et al, 2011). Thus, for the vast majority of the cases, the first objective of surgical management of an unknown PRT is an accurate histological diagnosis. Given the wide spectrum of tumor histology in this anatomical region, a correct diagnosis is essential for determining the post-operative adjuvant therapy and the need for metastatic workup, for defining a reliable prognosis and for planning a long-term follow-up (Bruce & Ogden, 2004; Konovalov & Pitskhealuri, 2003). There are three surgical strategies to obtain tissue from a PRT: stereotactic biopsy, endoscopic biopsy and open microsurgical procedure. Stereotactic biopsy is associated with a minor degree of invasiveness and a low risk of complication and it should be strongly considered especially in those patients with a known primary systemic tumor, in case of multiple lesions or in patients with medical contraindications to lengthy surgery and general anesthesia (Bruce & Ogden, 2004). Furthermore, if the MRI appearance of the tumor is strongly compatible with a germinoma, a biopsy (stereotactic or endoscopic if feasible) should be the first choice in order to avoid an unnecessary craniotomy (De Tribolet, 2009). The main disadvantage of a simple bioptic procedure is the limited amount of tissue that can be obtained, thus increasing the possibility of an incorrect diagnosis even for experienced neuropathologists (Moise et al, 2011). In one study, where stereotactic biopsy was followed by open surgery for resection (also if not only for PRTs), bioptic diagnosis was incorrect with clinical implications in about 7% of the cases and incorrect without clinical implications in 30% of the cases (Chandrasama et al, 1989). Stereotactic biopsy, mainly with the use of frame-based image-guided systems, can be performed with mild sedation and local anesthesia. The most common trajectories are the anterolateral-superior approach, originating anterior to the coronal suture and lateral to the mid-pupillary line, and the posterolateral-superior approach through a parieto-occipital junction entry point, for tumors with a significant lateral extension. The hemorrhagic potential of a stereotactic biopsy in the pineal region is relatively high compared to other anatomical sites given the adjacent venous system, the presence of choroidal arteries, the multiple pial surfaces traversed with needle and the lack of tissue turgor provided by adjacent cisternal and ventricular spaces which limit the possibility to tamponade even minor bleeding (Bruce & Ogden, 2004; Moise et al, 2011). Nevertheless, there is no significant difference in clinical-evident complication rate between pineal region biopsies and biopsies of other regions of the brain. Peri-operative mortality is less than 2%, permanent major morbidity 0-1.2% and transient minor morbidity 7-8.4%. Diagnostic useful sample is 87-97% but diagnostic accuracy is around 90% (Moise et al, 2011). A bioptic specimen may be obtained also through an endoscopic approach in association with an ETV in case of hydrocephalus. If a rigid endoscope is used, two different

trajectories are needed, but in selected cases a simultaneous procedure is possible with a flexible endoscope. There are only few reported series with a significant number of patients and the main limitations are the same of stereotactic procedures (hemorrhage and limited tissue sampling). Diagnostic yield is between 63 and 100%, and peri-operative mortality and morbidity seem acceptable (Bruce & Ogden, 2004; Moise et al, 2011). Open microsurgery, even if more invasive than stereotactic biopsy or endoscopy, permits to obtain an adequate amount of neoplastic tissue for a correct histological diagnosis in virtually all cases and offers a potential chance of cure for benign and low-grade lesions (pineocytoma, mature teratoma, meningioma, epidermoids) if a gross-total resection is achieved (Bruce & Ogden, 2004). For malignant tumors the oncological benefit of a maximal resection has not been definitely proved, but several studies found a correlation between the extent of tumor exeresis and an improved response to adjuvant therapy and increased survival, at least for certain histological subtypes. Furthermore, standard microsurgical techniques allow the restoration of CSF flow, obviating the need for CSF diversion procedures; moreover, a “second-look” surgery is also a potential useful strategy to remove residual tumor following radio and/or chemotherapy for malignant neoplasms (Moise et al, 2011). Two main surgical approaches are used to remove a PRT: the supracerebellar-infratentorial approach and the occipital-transtentorial approach. The choice between them is based on the anatomical features of the tumor but also on the experience and the preference of the surgeon (Bruce & Ogden, 2004; De Tribolet, 2009; Konovalov & Pitskhealuri, 2003). With the modern microsurgical skills and the neurocritical care, in the major series reported in the last 15 years mortality is less than 5%, major morbidity less than 6% but permanent minor morbidity is still reported in up to 28% of the cases (Moise et al, 2011). Hemorrhage is the most serious complication of any surgical approach to the pineal region, especially for malignant tumors with abnormal neovasculature incompletely resected. Bleeding in the surgical field may occur immediately after surgery as well as with a delay of several days. Specific neurological sequelae, generally transient and reversible over a period ranging from days to up to 1 year, are ataxia, papillary abnormalities and extraocular movement dysfunction because of cerebellar and/or brainstem manipulation, but also visual field disturbances after the occipital-transtentorial approach may occur. Prior radiation therapy, invasive/malignant tumors and pre-operative neurological symptoms, increase the risk and severity of post-operative complications (Bruce & Ogden, 2004; De Tribolet, 2009; Moise et al, 2011).

6.2 Germ cell tumors

Localized germinomas should be managed with radiation therapy alone, including ventricular or whole brain irradiation followed by a tumor boost for a total dose of 45-50 Gy (Haas-Kogan et al, 2003). Craniospinal irradiation is indicated if there are signs of CSF dissemination (Kyritis, 2010). Patients with germinoma had a 5-year survival rate of 96% and a 10-year survival rate of 91-93% (Brastianos et al, 2010; Kkyritis, 2010). For mature teratomas complete resection is the treatment of choice (Kyritis, 2010). In case of immature forms, maximal safe resection may be followed by radio and/or chemotherapy on an individual basis and evidence of residual disease (Kyritis, 2010). Malignant teratomas as well as choriocarcinomas, embryonal carcinomas, endodermal sinus tumors and mixed tumors with a malignant component should be maximally resected and then treated with radiotherapy and chemotherapy (Echevarria et al, 2008; Matsutani, 2004). As for germinomas, craniospinal irradiation is necessary only if the tumor is disseminated. In mixed germ cell tumors, response

of the malignant component induced by radio and/or chemotherapy may spare the benign tumor part (Kyritsis, 2010). This residual tumor is likely to be mature teratoma and operative resection is useful and safe, also if a stereotactic radiotherapy is a possible alternative for small intracranial residual disease (Friedman et al, 2001; Kohyama et al, 2001). The 10-year survival rate is estimated to be 78-93% for mature teratomas and 45-86% for immature teratomas, (Brastianos et al, 2010; Kkyritis, 2010). NGGCTs are associated with a 20-75% of 5-year survival rate following radiotherapy with or without chemotherapy (da Silva et al, 2010). The survival of patients with mixed tumors is dependent on the malignant component of the neoplasm, with a 3-year survival rate ranging from 94% of mixed germinoma and teratoma to only 10% of mixed tumors of predominantly pure malignant elements (Brastianos et al, 2010; Kkyritis, 2010). Application of very aggressive protocol including surgery (also for residual disease), radio and chemotherapy in selected cases may sporadically result in complete response and long survival also in cases of disseminated intracranial germ cell tumors (Kageji et al, 2007; Kochi et al, 2003).

6.3 Pineal parenchymal tumors

Gross-total resection is the standard of care for pineocytomas (Blakeley & Grossman, 2006) and is associated with a 5-year overall survival rate of 86-91% (Dahiya & Perry, 2010). Radiation therapy may be reserved for those patients with an incomplete resection or recurrent disease (Brastianos et al, 2010). Recently, a retrospective analysis of a small cohort of patients treated with up-front stereotactic radiosurgery documented a 1-, 3- and 5-year survival rate of 100, 92.3 and 92.3%, but this results should be interpreted with caution as susceptible to various biases (Kano et al, 2009). Pineal parenchymal tumors of intermediate differentiation are very rare so that a therapeutic treatment is not yet standardized. For high-grade lesions an aggressive management with a combination of surgery, radio and chemotherapy is reasonable, whereas for low-grade tumors the benefit of a postoperative radiotherapy remains unclear, at least after a gross-total exeresis (Anan et al, 2006; Senft et al, 2008). Pineoblastomas are very aggressive tumors with a high propensity to CSF dissemination and local recurrence. A correct management should include maximal safe surgical resection followed by chemo and radiotherapy (Brastianos et al, 2010; Dahiya & Perry, 2010). Lutterbach and colleagues (Lutterbach et al, 2002) reported the largest series (retrospective and multicentric) to date regarding malignant PPTs (pineoblastoma and pineal parenchymal tumors of intermediate differentiation) in adult. Median overall survival of pineoblastomas was 77 months with a 5- and 10-year rate of 51% and 23% respectively. Median overall survival of pineal parenchymal tumors of intermediate differentiation was 165 months with a 5- and 10-year rate of 80% and 72%. Taken together, residual disease after initial treatment (no or minimal residual disease vs major residual disease), histology (pineoblastoma vs pineal parenchymal tumor of intermediate differentiation) and extent of disease (localized vs disseminated) were independent prognostic factors for overall survival. As for pineocytomas, also for pineoblastomas stereotactic radiosurgery has been investigated as a primary treatment modality with conflicting results. In one retrospective study seven patients with pineoblastomas or mixed pineal parenchymal tumors were submitted to stereotactic radiosurgery with a 1-, 3- and 5-year survival rate of 87.5, 57.1 and 28.6% respectively (Kano et al, 2009). In an older retrospective study stereotactic radiosurgery was used as the sole treatment or as an adjuvant therapy in four patients with pineoblastomas who died in a range of 7-56 months

after diagnosis (Hasegawa et al, 2002). Finally, a possible alternative approach is interstitial brachytherapy but the number of patients treated with this strategy is too small to draw final conclusions (Julow et al, 2006).

6.4 Papillary tumor of the pineal region

Papillary tumor of the pineal region is a rare and recently described neoplasm with a tendency to local recurrence (51% in a recent series) (Fèvre-Montange et al, 2006). There is still no defined treatment protocol but aggressive local therapy with maximal surgical resection and adjuvant radiotherapy has been suggested (Dahiya & Perry, 2010). Nevertheless, the role of postoperative radiation therapy is debated. Despite clear-cut histological criteria have yet to be defined, most papillary tumors of the pineal region correspond to low-grade malignancy (WHO grade II) and 5-year estimated overall survival and progression-free survival are approximately 73% and 27% respectively. Mitotic index higher than 5 per 10 HPFs and residual disease after surgery are correlated with recurrence and decreased survival (Fèvre-Montange, 2006).

6.5 Other tumors

Pineal region meningiomas, originating at the level of the velum interpositum, should be surgically removed with a goal of gross-total resection as in all other sites (Brastianos et al, 2010). In a cohort of ten patients operated for a meningioma of the pineal region in all but one case there was no local recurrence at 3-year follow-up (Konovalov et al, 1996). There is still no general consensus for the treatment of gliomas of the pineal region. Given the fact that most of these tumors are small, localized in the tectal region, without contrast enhancement and with a very indolent course, the preferred approach seems to be a close radiological follow-up with surgical management of an eventual hydrocephalus (Daglioglu et al, 2003; Yeh et al, 2002). When a clinical and/or radiological progression is observed a stereotactic biopsy should be considered in order to properly define histology and radiotherapy and/or chemotherapy are recommended (Brastianos et al, 2010).

7. Surgical approaches

7.1 Anatomical background

Surgery of the pineal region tumours is a challenge for most neurosurgeons because of the variety of pathologies but mainly for the very deep anatomical location. Pineal region corresponds to the posterior tentorial incisural space (Rhoton, 2000). It lies in front of the cerebellum and behind the midbrain into the cerebello-mesencephalic fissure and is related with the quadrigeminal cistern (Rhoton & Ono, 1996; Yasargil, 1984). It extends upward to the lower surface of the splenium and backward to the level of the tentorial apex. Laterally its boundaries are the pulvinar of thalamus and the posterior parahippocampal gyrus but it continues in the middle or lateral incisural space.

7.2 Anesthesia considerations

Surgical procedures are done under standard general anesthesia. If sitting position is used, a central venous catheter should be placed and trans-oesophageal Doppler monitoring should

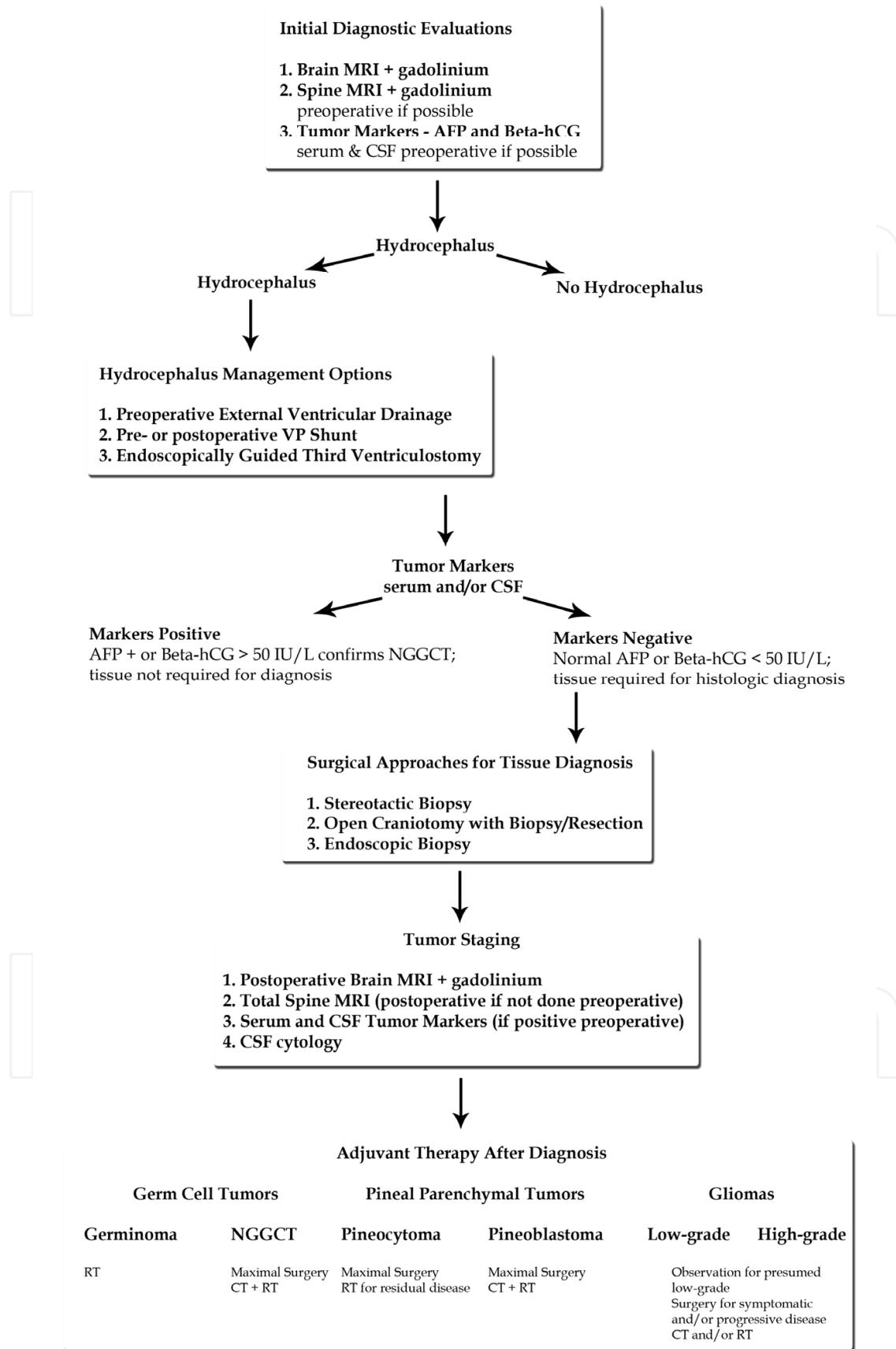


Table 2. Algorithm for diagnosis and treatment of PRTs (for more details see text)

be done for the risk of air embolism. When hydrocephalus is present, particular care should be reserved to increased intracranial pressure and a pre-operative external ventricular drainage, in sitting position, is preferable to prevent hypertensive pneumocephalus.

7.3 Operative approaches

Several approaches were so far developed to improve the exposure of the pineal region but basically they are categorized as either supratentorial or infratentorial approaches. The supratentorial approaches include the posterior interhemispheric tranccallosal (Dandy, 1921), the occipital transtentorial (Foerster, 1928; Jamieson, 1971; Poppen, 1966; Lapras, 1987) and the very rarely used transtemporal-transventricular (Van Wagenen, 1931) approach. The exposure merely through the posterior fossa is achieved by the infratentorial-supracerebellar approach. Supra/infratentorial-transinus approach (Sekhar & Goel 1992; Ziyal et al, 1998), combining both supratentorial and infratentorial perspective, provide wider exposure of the pineal region but they are longer procedures with more risk of morbidity. Choosing amongst different surgical routes is mainly related to the size and location of the lesion to treat as well as to the surgeon's experience and preference with a specific approach. Generally supratentorial approaches are suitable for pineal lesions displacing downward the Galen's Vein complex; lesions developing below the level of the Galen's vein complex and displacing it upward are better managed through the infratentorial avenues. This allows dealing with pineal region tumors with less risks of damage of so crucial venous structures.

7.4 Patient positioning

Depending which approach is selected different position can be used, although the same position is suitable for more approaches.

7.4.1 Sitting position

It is most commonly used for infratentorial-supracerebellar approach (Bruce, 1993). The head is fixed neutrally and moderately flexed, until tentorium is nearly parallel to the floor (Fig. 1). Caution should be taken to maintain two-finger breadth between chin and sternum to avoid compression of superior airways and jugular veins and consequent intracranial high venous pressure. After dural opening cerebellum spontaneously falls down offering a natural corridor below the inferior aspect of tentorium. At the depth of exposure anatomical landmarks are better recognizable, moreover fluids, CSF or blood, are continuously drained resulting in an always clean surgical field. On the other hand sitting position is often very tiring for the surgeon and complications are represented by air embolism, pneumocephalus and subdural haematoma (Bruce & Stein, 1993).

7.4.2 Lateral position

Patient is positioned in lateral decubitus with the non-dominant hemisphere in dependent position (McComb & Apuzzo, 1988). The head is rotated 30 degrees toward the floor. A variation of lateral position is the three-quarter prone position, where the head is at an oblique 45 degrees angle with the non dominant hemisphere dependent (McComb & Apuzzo, 1987; Ausman et al, 1988). Both positions are used for occipital-transtentorial

approach because the dependent hemisphere is easily retracted from the falco-tentorial junction with the aid of gravity. It is more comfortable for the surgeon but positioning could be time-consuming and demanding for O.R. personnel.

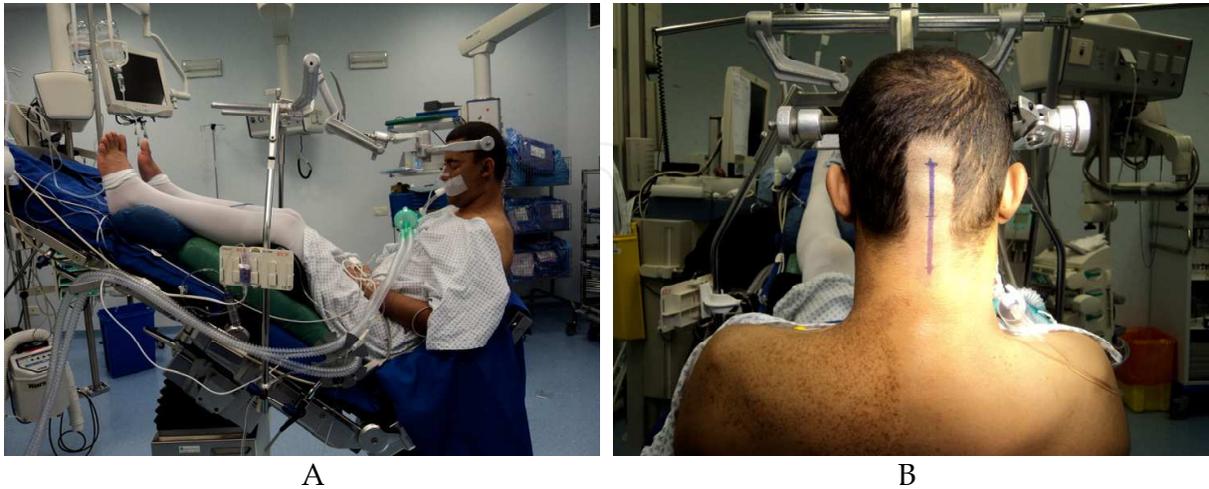


Fig. 1. The sitting position for the infratentorial-supracerebellar approach. (A) The head is moderately flexed bringing the tentorium almost parallel to the floor. The inferior limbs are positioned higher than the level of heart to support venous pressure and prevent air embolism (B) The head is fixed with Mayfield head rest in neutral position. Median longitudinal skin incision is made from 2 cm above the inion down to C3 level.

7.4.3 Prone position

Is the simplest and fastest position to set up. Generally used for pediatric patients and for supratentorial approaches (Bruce et al., 1996). The head is neutrally fixed and slight flexed but the anatomical landmarks are inverted. Fluids stay in the field and need to be continuously aspirated getting the procedure slow. Venous drainage is not facilitated and brain or cerebellum swelling could occur. A variation is represented by Concorde position with the head rotated 15 degrees away from the side of craniotomy (Kobayashi et al, 1983).

7.5 Infratentorial procedures

7.5.1 Infratentorial-supracerebellar approach

The classic median infratentorial-supracerebellar approach was first described by Horsley, in 1910 and Krause in 1926; then it was refined and popularized by Stein in 1971. More recently extensions of the original approach were developed: the paramedian approach (Yasargil, 1984) and the extreme-lateral approach (Vishteh et al, 2000) to the lateral tentorial incisural region, the supracerebellar-transtentorial approach (Yonekawa et al., 2001) to the posterior parahippocampal gyrus. For the median approach the sitting position is generally preferred. After a midline incision extending from 2 cm above the inion down to the level of C3 or C4 spinous process, a median suboccipital craniotomy is performed; the Torcular and adjacent transverse sinuses are skeletonized. Posterior edge of foramen magnum is not routinely opened but this maneuver facilitates opening the cisterna magna to release CFS. Every effort should be done to avoid air embolism waxing patent veins of the bone. The dura is opened in a gentle curvilinear fashion along the inferior margin of both transverse

sinuses, and retracted upward via tacking suture. Almost complete exposure of transverse sinuses is necessary to avoid compression of the sinuses against the edge of craniotomy; moreover it permits a more angled vision through the microscope, in a cranio-caudal direction. If the posterior fossa is tight, opening arachnoid of cisterna magna allows releasing CFS. Cerebellum falls down spontaneously for gravity, opening the anatomical corridor below the tentorium. Under microscope magnification, severing the bridging veins between cerebellum and tentorium is a crucial point to gain the corridor carrying out the approach through. As some authors reported (Ueyama et al., 1998; Bruce & Stein, 1993; Fain et al., 1994; Page 1977), bridging veins in the midline can be sacrificed but this could lead to cerebellar venous infarction and consequent swelling. The arachnoidal adhesions should be released on the surface of cerebellum and all along the tentorial incisura as well, where they are particularly thickened. This allows pushing down the cerebellum and provides a large exposure of the region up to the apex of tentorium where the venous complex of Galen drains into the straight sinus, inferior to the splenium. Just below, the pineal gland and the posterior wall of third ventricle are visualized. Laterally the medial part of the pulvinar of thalamus borders the surgical field (Ammirati et al., 2002). Easy access to superior collicles is provided but the culmen vermis may limit the exposure of the inferior half of the quadrigeminal plate. Without splitting the vermis, a more angled vision through the microscope in a cranio-caudal direction together with an extensive and meticulous opening of the cerebello-mesencephalic fissure give the full exposure of the quadrigeminal plate down to the inferior collicles (Bricolo, 2000). Thus, the inferior limit of exposure would be considered the frenulum of inferior medullary velum with the origin of the trochlear nerve bilaterally (Fig. 2). The operative fields in very deep and extralong instruments are necessary together with a free-standing armrest to avoid surgeon's fatigue. When the tumor is encountered, posterior aspect of the capsule is sharply opened and internal debulking is done. Soft tumour could be easily decompressed by suction, after having taken some specimens for histological analysis. For decompression of solid tumors ultrasound aspirator is strongly recommended. Maintaining tumour capsule facilitate the dissection from surrounding structures. Whenever is possible total removal of the tumor should be achieved. When the lesion infiltrates the surrounding structures a sub-total or partial resection is justified, although residual tumor increases the risk of postoperative bleeding. A very careful hemostasis should be done and a watertight closure of the dura is mandatory. Craniotomy and skin closure are accomplished in the usual manner.

7.6 Supratentorial procedures

7.6.1 Posterior interhemispheric transcallosal approach

The posterior interhemispheric transcallosal approach was proposed by Dandy in 1921 and popularized later by Yasargil for splenial and parasplenial lesions. It is suitable for lesions growing in pineal region below the level of the Galen's Vein complex (McComb et al., 1998). All positions could be used although sitting and prone positions have the advantage to allow a straight midline trajectory. Parieto-occipital craniotomy is performed, across the posterior third of superior sagittal sinus. Dura is opened in C-shaped fashion and reflected toward the midline. The approach is centered over the parietal lobe and every effort should be made to avoid tearing the bridging vein. It is preferable do not sacrifice more than one. Gently retracting the hemisphere laterally and releasing arachnoidal adherence with the falx, the interhemispheric fissure is open. It is the surgical corridor leading to the splenium of corpus callosum identified by the white appearance. Retracting the parietal lobe instead of

the occipital lobe allows avoiding visual field impairment. 2 cm callosotomy is made at the splenium and the lesion is identified in the velum interpositum, below the internal cerebral veins. Tumor occupied most of the exposure and it is interposed between the surgeon and caudal structure of the pineal region. Quadrigeminal plate and posterior choroidal artery are hidden until the tumor has been debulked and mostly removed at the end of the procedure. For this reason the posterior interhemispheric transcallosal approach is replaced in most case by the occipital-transtentorial approach or the infratentorial-supracerebellar approach and is used mainly for lesions expanding into the third ventricle as well as those extending upward in the corpus callosum (Hoffman, 1984; Rhoton et al., 1981).

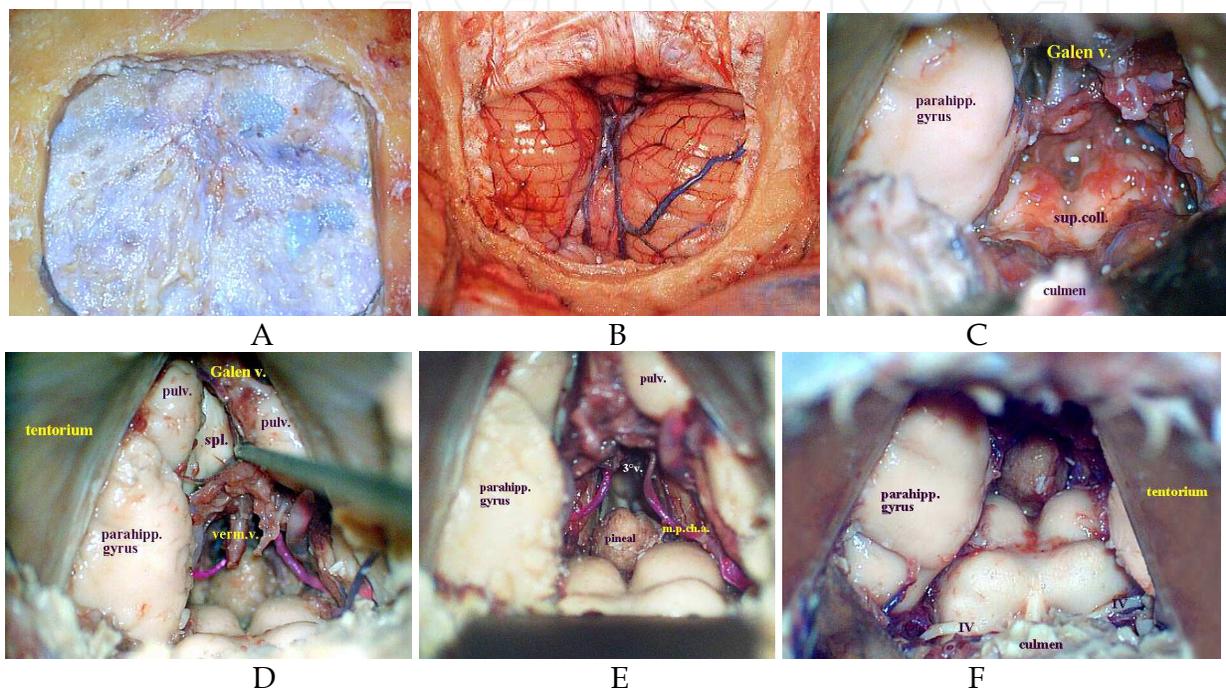


Fig. 2. Stepwise median infratentorial-supracerebellar approach in cadaveric specimen. (A) The median suboccipital craniotomy. The Torcular Herophili and the proximal part of both transverse sinuses are completely exposed. (B) After dural opening, bridging vein between the tentorial surface of cerebellum and the tentorium are severed allowing downward retraction, by self-retaining retractor, of the cerebellum. This gives access to the infratentorial-supracerebellar corridor. (C) Retraction of the culmen vermis exposes the Galen vein's complex (Galen v.) at tentorial apex and, below it, the superior collicles (sup.coll.) still covered by the deep arachnoidal layer of quadrigeminal cistern. Through the posterior tentorial incisura variable amount of the posterior parahippocampal gyrus (parahipp. gyrus) protrudes in the posterior incisural space. (D) Retraction of the vein of Galen (Galen v.) exposes the splenium of corpus callosum (spl.). Laterally both pulvinar thalami (pulv.) are evident. Severing the superior vermian veins (verm. v.) allows exposing the pineal gland and quadrigeminal plate. (E) Pineal gland (pineal) lies immediately above the quadrigeminal plate. Superiorly, dissecting the velum interpositum, the posterior third ventricle (3° v.) is entered. Laterally to the pineal gland the posterior medial choroidal arteries (p.m.ch.a) course toward the roof of the third ventricle. (F) Moving the microscope angle in a more cranio-caudal direction, through a careful and meticulous dissection of the cerebello-mesencephalic fissure, a complete exposure of quadrigeminal plate is achieved, down to the frenulum of superior medullary velum and the origin of both trochlear nerves (IV).

7.6.2 Occipital-transtentorial approach

The occipital-transtentorial approach was proposed by Foerster in 1928, described in detail by Poppen (1966) and popularized by Jamieson (1971). It is performed generally in lateral three-quarter prone position (Moshel et al., 2009) with non-dominant hemisphere dependent. Occipital craniotomy is carried out across superior sagittal sinus and Torcular. Dura is open in C-shaped fashion, reflected toward midline and retracted away from the Torcular via tack-up sutures. Lateral decubitus provides spontaneous falling down of occipital pole, minimizing retraction. The corridor along falco-tentorial junction is gained and the posterior tentorial incisura is reached. The Galen's vein complex comes into nice view but the exposure is widely enhanced by cutting the tentorium 1,5 cm lateral and parallel to the straight sinus, from the point anterior to the transverse sinus to the free edge (Moshel et al., 2009). Cutting the falx and the tentorium bilaterally, the exposure is enormously enlarged from the splenium cranially to the bottom of the cerebello-mesencephalic fissure caudally (Kawashima et al., 2002). All structures of the pineal region are well controlled as far as the quadrigeminal plate, although deep venous structures are somehow interposed between the surgeon and the tumor. The exposure is often excellent but the quite oblique perspective can disorient the surgeon. Moreover retraction of the occipital pole, although protected, gives the risk of visual field deficit. For the wide exposure of the pineal region that it can afford, the occipital-transtentorial approach represents an alternative to the infratentorial-supracerebellar approach.

8. Case report

A 60-year-old woman was admitted with two months history of headache and blurring vision. She complained of weakness of legs and balance disturbances. Neurological examination revealed only a slight ataxia. MRI of the brain showed a huge rounded well-enhanced lesion in the pineal region, suspected of meningioma, extending above and below the tentorium through the posterior tentorial incisura. Caudally dorsal midbrain was compressed and the Sylvian aqueduct partially obstructed with consequent triventricular hydrocephalus. Cranially the lesion reached the splenium of corpus callosum, displacing the venous structures of Galen's vein complex (Fig. 3). According to Yasargil classification (Yasargil, 1996) the tumor looked a type 3 tentorial meningioma, arising from the posterior incisura. Digital angiography, after selective injection of the left internal carotid artery, showed a slight tumour blush, supplied by Bernasconi and Cassinari artery; in the venous phase a partial obstruction of the straight sinus was evident (Fig. 4). Considering the posterior attachment to the tentorium and the cranial displacement of the Galen's vein complex, the infratentorial-supracerebellar approach was believed the most appropriated to deal with the tumor. The patient was operated in sitting position and a median suboccipital craniectomy was carried out and extended to the torcular. The dura was opened flush to the torcular and proximal trasverse sinuses' inferior border that was lifted via tack up sutures. The huge meningioma was exposed through the infratentorial-supracerebellar corridor and gradually debulked with ultrasound aspirator. It was detached from the posterior tentorial edge, gently separated from the surrounding neuro-vascular structures and totally removed in a piecemeal fashion. Postoperative course was uneventful and the patient was discharged seven days after surgery. At discharge neurological ataxia was moderately worsened but recovered completely at six months follow-up. Histological examination documented a

meningothelial meningioma (WHO Grade I). Postoperative and three year follow-up MRIs confirmed total removal and no recurrence of the lesion (Fig. 5).

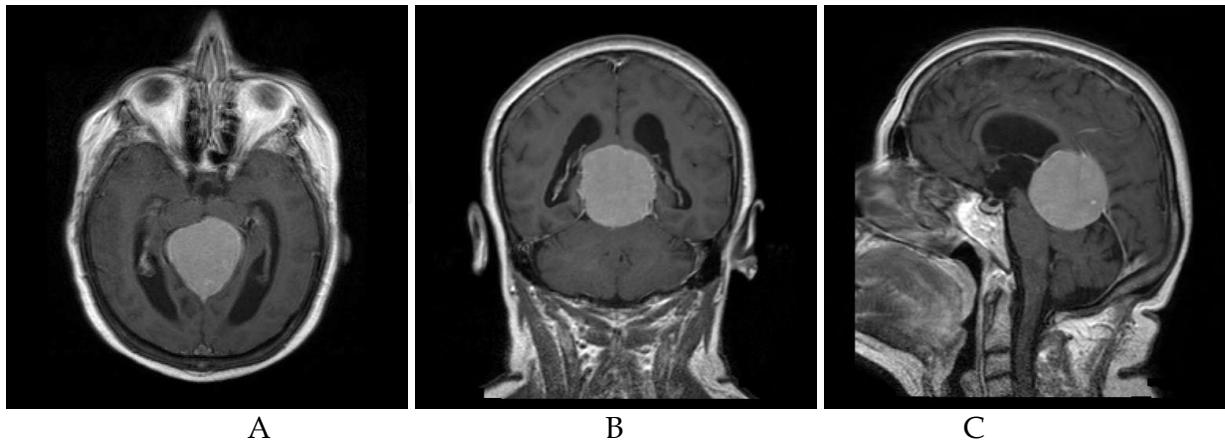


Fig. 3. Axial (A), coronal (B) and sagittal (C) preoperative MRI.

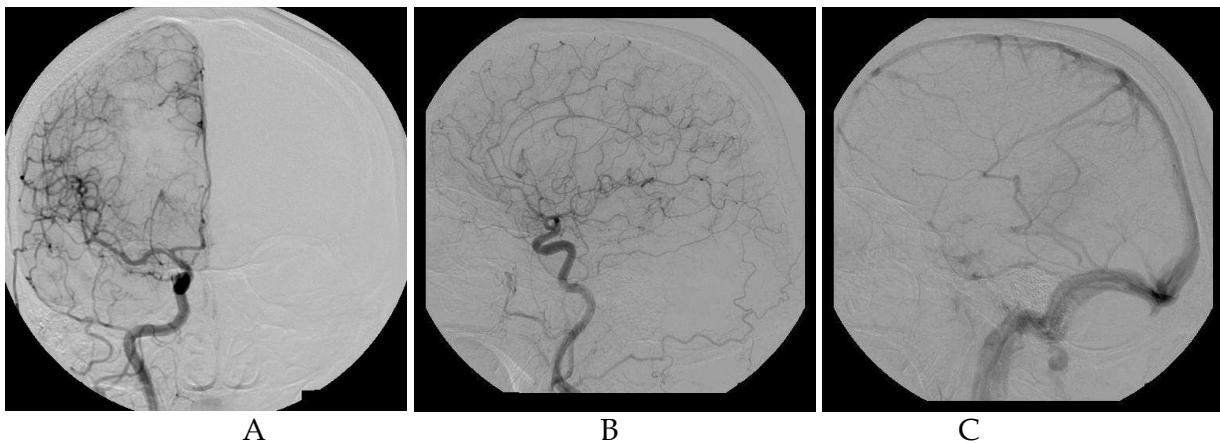


Fig. 4. Preoperative angiography. Slight tumor blush is visible supplied by Bernasconi and Cassinari artery (A-B). In venous phase straight sinus is minimally filled.

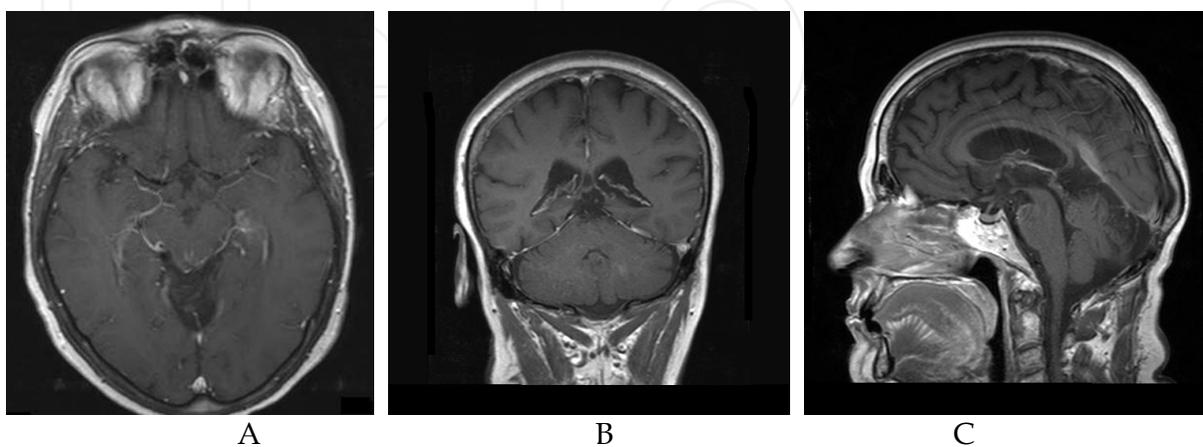


Fig. 5. Axial (A), coronal (B) and sagittal (C) three year follow-up MRI. The tumor was totally removed. No recurrence is evident.

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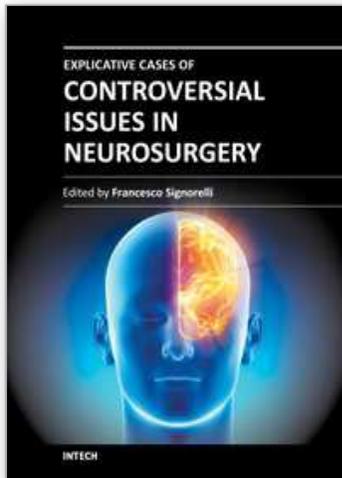
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Explicative Cases of Controversial Issues in Neurosurgery

Edited by Dr. Francesco Signorelli

ISBN 978-953-51-0623-4

Hard cover, 534 pages

Publisher InTech

Published online 23, May, 2012

Published in print edition May, 2012

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