Chapter 10
Choroid Plexus Tumors

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Abstract Choroid plexus tumors are rare tumors, predominantly found in pediatric patients. Lower grade tumors histologically resemble native choroid plexus while higher grade lesions are progressively more disordered and less differentiated. They are commonly associated with hydrocephalus and usually present with symptoms of that condition. Complete resection is typically curative in the case of low grade lesions. Higher grade lesions may be treated with adjuvant chemotherapy or radiotherapy. The hydrocephalus often resolves but in some cases may persist after resection and may require additional treatment.

10.1 Introduction

Tumors arising from the choroid plexus are relatively rare. They comprise less than 1% of all intracranial tumors (Cannon et al. 2015). Guerard made the first detailed notes of a choroid plexus tumor in his autopsy report of a 3 year-old female in 1833. His notes were recorded in a publication by Davis and Cushing (1925). The first recorded attempt of surgical removal occurred in 1906 and the first known surgery resulting in long-term survival of the patient occurred in 1919 (Unger 1906). Over the subsequent few decades, surgical resection of these intraventricular tumors was

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refined, with Dandy pioneering the transcallosal route to the third ventricle in 1922 and Masson developing the transfrontal approach in 1933 (Dandy 1922; Masson 1934). Until the past two decades, the surgical mortality of these often vascular tumors remained high (Guidetti and Spallone 1981).

10.2 Epidemiology

Choroid plexus tumors are divided into the World Health Organization (WHO) Grade I choroid plexus papilloma (CPP), the Grade II atypical choroid plexus papilloma (aCPP), and the malignant Grade III choroid plexus carcinoma (CPC). Approximately 80% of all choroid plexus tumors are CPPs (Borja et al. 2013).

Choroid plexus tumors may occur at any age, however they are more common in the pediatric population. They comprise 2–4% of intracranial tumors in children, but up to 20% of tumors present within the first year of life (Ostrom et al. 2014; Thomas et al. 2015). The overall incidence of choroid plexus tumors is approximately 0.22–0.3 per 100,000 children (Cannon et al. 2015; Lafay-Cousin et al. 2011). Over 80% of all CPCs occur in patients less than 18 years; the median age of patients with CPCs is 3 years (Sun et al. 2014a). While most tumors are sporadic, there may be predisposing genetic factors. CPPs have been found in siblings and may be associated with specific genetic syndromes (Gozali et al. 2012).

The anatomic location of the tumor varies with age; tumors in children are most commonly located within the lateral ventricles. Large series do not show a predilection for one side; although there was a commonly held belief that left-sided tumors were more common (Boyd and Steinbok 1987; Knierim 1990; McGirr et al. 1988; Spallone et al. 1990). The most common tumor location in adults is within the fourth ventricle. The median age of all choroid plexus tumors is 3.5 years. The median age for tumors found in the fourth ventricle is 22.5 years (Wolff et al. 2002). There are rare reports of choroid plexus tumors in the cerebellopontine angle (the anatomic area defined by the junction of the pons and the cerebellum), third ventricle, or cerebral parenchyma.

CPPs are generally solitary. Multifocal or disseminated CPPs have been reported in adults, but are rare (Abdulkader et al. 2016; Doglietto et al. 2005; Jagielski et al. 2001; Karim et al. 2006; Morshed et al. 2017; Peyre et al. 2012; Scholsem et al. 2012; Serifoglu et al. 2016; Zachary et al. 2014). Multifocal or metastatic lesions are more common in higher grade tumors. Multiple lesions occur in approximately 17% of patients with aCPP (Jinhu et al. 2007; Wrede et al. 2009). Multifocal choroid plexus tumors have been rarely reported in children, often in patients with either high-grade tumors or genetic conditions such as Aicardi syndrome, an X-linked dominant disorder characterized by agenesis of the corpus callosum, infantile spasms, and lacunar chorioretinopathy (Pianetti Filho et al. 2002; Taggard and Menezes 2000; Trifiletti et al. 1995).

10.3 Clinical Presentation and Evaluation

Choroid plexus tumors often present with manifestations of hydrocephalus including headache, vomiting, lethargy, or papilledema (swelling of the optic disc noted on ophthalmologic examination) (Lena et al. 1990). The hydrocephalus may cause an abrupt decline with rapid deterioration and herniation signs including bradycardia, hypertension, and coma (Picht et al. 2006). Herniation signs indicate a dangerously elevated level of intracranial pressure that, if uncorrected, is rapidly fatal. Young children without fused cranial sutures may present with a tense fontanelle or macrocephaly. Other documented presentations include irritability, failure to thrive, developmental delay, cranial nerve palsy, endocrine disturbances, "bobble-head" phenomenon, anorexia, schizophrenia, spontaneous cerebrospinal fluid leak from the nose or ears, and titubation, a characteristic uncontrollable rhythmic tremor of the head (Arasappa et al. 2013; Lechanoine et al. 2017; Nagib and O'Fallon 2000; Singh et al. 2017). Rarely, patients present with rapid decline from tumor hemorrhage (Pandey et al. 2016).

10.3.1 Radiographic Evaluation

A computerized tomography (CT) scan is often the first imaging modality employed in patients with choroid plexus tumors. A CT scan clearly shows the ventricle size and allows assessment of the degree of hydrocephalus. Choroid plexus tumors may be calcified, a feature best appreciated on CT scan. CPPs are isodense to hyperdense on non-contrasted CT scanning (Fig. 10.1a). They appear lobulated and often have a "cauliflower" appearance. Tumors often brightly enhance with administration of iodinated contrast agents. Patients may have diffuse enhancement of the meninges surrounding the brain, suggesting infection or tumor spread. However, meningeal enhancement often resolves completely after removal of the primary tumor (Scala et al. 2017). CPPs are generally contained within a ventricle and show a clear distinction from surrounding brain parenchyma. Aggressive aCPPs may have partially blurred borders with the parenchyma and CPCs may show frank invasion. Images of all choroid plexus tumors may show mild to moderate peritumoral edema (Shi et al. 2017a).

Choroid plexus tumors have characteristic features with magnetic resonance imaging (MRI). MRI provides greater detail than CT scanning and is the imaging modality of choice. They are hyperintense on T2-weighted images (Fig. 10.1b). Choroid plexus tumors are iso- to hypointense to gray matter on T1-weighted images (Fig. 10.1c). Choroid plexus tumors often show homogenous and intense enhancement with gadolinium contrast (Fig. 10.1d) (Kim et al. 2012; Shi et al. 2017b). Rarely, tumors exhibit heterogeneous enhancement. It is difficult to distinguish CPPs from CPCs based on imaging alone, however CPCs often show heterogenous contrast enhancement, invasion of the parenchyma, and robust peritumoral edema (Salunke et al. 2014; Taylor et al. 2001).

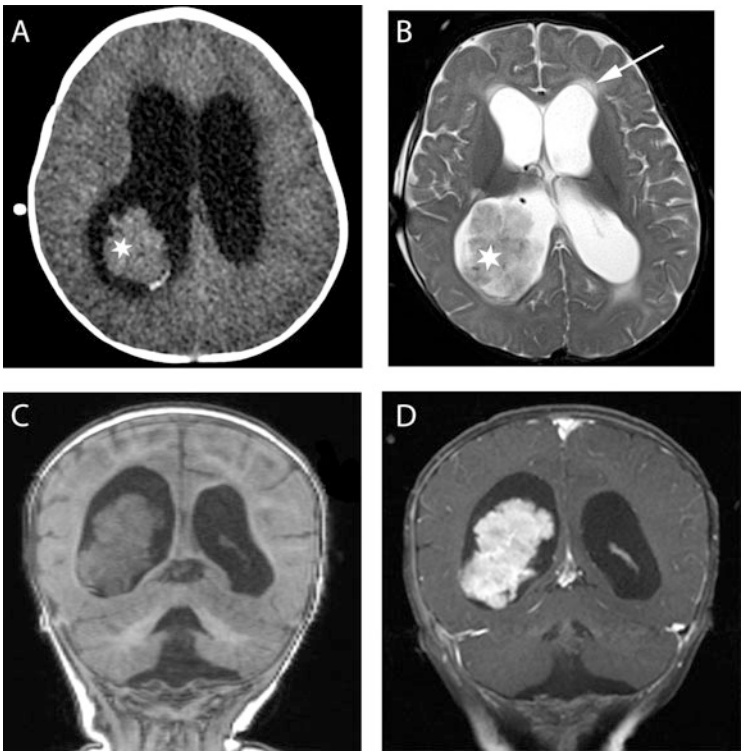

Fig. 10.1 (**a**) Axial image in a non-contrasted CT scan of the head in a 5 month-old child shows hydrocephalus with a choroid plexus papilloma in the right lateral ventricle that is isodense to surrounding brain and shows a small amount of bright calcification on the posterior border (star). (**b**) Axial T2-weighted MRI in the same patient demonstrates the tumor (star) and transependymal flow (arrow), the bright area around the frontal horn of the ventricle indicative of elevated intraventricular pressure from hydrocephalus. (**c**) Coronal non-contrasted T1-weighted MRI demonstrates the large tumor in the lateral ventricle. (**d**) The tumor brightly and homogenously enhances with gadolinium contrast

Diffusion-weighted images (DWI) and apparent diffusion coefficient (ADC) images are MRI sequences that generate pictures based on diffusion of water in cells. These imaging modalities are complementary to the standard imaging techniques. In pediatric tumors, the cellular density correlates with DWI and ADC findings. This may be used to predict the degree of malignancy of a tumor, as higher-grade tumors are often more cellular than lower grade ones. However, choroid plexus tumors may be any density on DWI. There is no difference of these values between grades of tumor and thus the prognostic value of these sequences is limited (Shi et al. 2017a).

MR spectroscopy measures cellular metabolites and is helpful in evaluating the diagnosis and grade of brain tumors. The general finding in brain tumors is an elevated choline peak and decreased *N*-acetyl aspartate (NAA) peak compared to

normal brain. Choroid plexus tumors are characterized by an elevated choline peak and absence of NAA (Borja et al. 2013). A higher peak of the metabolites Cho and myoinositol may be useful in differentiating CPCs from CPPs (Borja et al. 2013; Horska et al. 2001; Krieger et al. 2005).

The radiologic differential diagnosis of intraventricular tumors includes ependymomas, meningiomas, central neurocytomas, subependymal giant cell astrocytomas, colloid cysts, astrocytomas, and pineal region tumors. A rare intraventricular tumor is the choroid plexus adenoma. This tumor is distinct from the standard choroid plexus tumor. An adenoma is characterized by well-differentiated tubular glands and lacks the characteristic findings of the standard choroid plexus tumors (Prendergast et al. 2018).

10.4 Histopathology

10.4.1 Gross Pathology

Choroid plexus tumors appear as cauliflower-shaped fronds, with a greyish or brownish-tan appearance. CPPs are well circumscribed and generally separate easily from the ventricular ependymal lining. They are typically soft, but may develop calcifications, hemorrhages, or cystic features (Gaudio et al. 1998). aCPPs appear grossly like CPPs but may have irregular and possibly invasive margins (Safaee et al. 2013a). As opposed to CPCs, aCPPs lack *necrosis*, the finding of intratumoral cellular death that indicates a rapidly progressing, aggressive tumor whose expansion exceeds its blood supply. CPCs are less circumscribed, invade normal brain parenchyma, and may contain areas of necrosis (Gopal et al. 2008).

10.4.2 Microscopic Pathology

Normal human choroid plexus is shown in Fig. 10.2. This structure is characterized by a single layer of cuboidal epithelial cells lining finger-like papillary structures with fibrovascular cores. The epithelial cells have central, uniform round-to-oval nuclei and eosinophilic cytoplasm. Physiologic calcifications are commonly encountered and increase in frequency with patient age (Fig. 10.2, arrow).

Choroid plexus tumors are graded based on histological findings. Low grade tumors are very similar to normal choroid plexus. Higher grade tumors are distinguished by elevated cellular mitotic activity, histological necrosis, loss of papillary architecture, increased cellularity, and nuclear asymmetry or pleomorphism. Brain invasion may occur with all three grades, although it is rare with CPPs and common with CPCs.

CPPs (WHO Grade I) are microscopically similar to normal choroid plexus. They are characterized by well-formed papillary structures containing fibrovascular cores

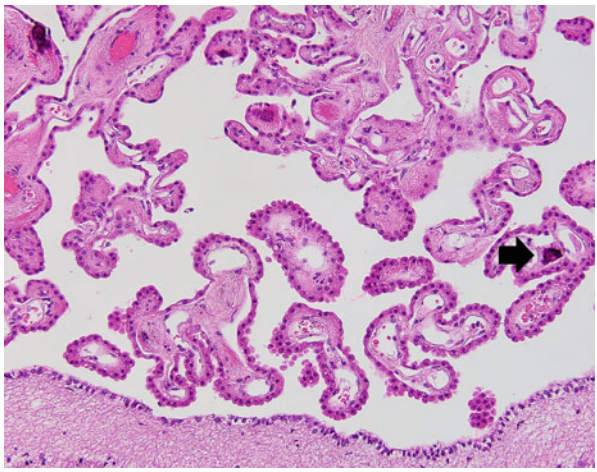

Fig. 10.2 Normal human choroid plexus (200× magnification) consists of fingerlike fibrous papillary structures lined by a single layer of uniform cuboidal cells. Physiologic calcifications (arrow) are common and increase in frequency with age

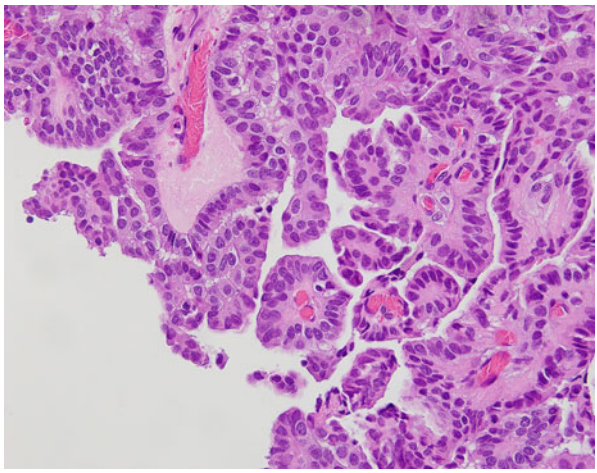

Fig. 10.3 Choroid plexus papilloma (400× magnification) is a WHO Grade I tumor which closely resembles normal choroid plexus. By definition, the mitotic rate is <2 mitoses/high-powered field

and lined by a single layer of cuboidal to columnar epithelial cells (Fig. 10.3). However, the cells are more elongated and crowded in a higher density than normal choroid plexus. CPPs have a well-defined basement membrane and low mitotic activity (<2 mitosis per 10 high-powered fields). CPPs may have small areas of higher-grade features, but they are rare. Brain invasion is typically absent (Louis et al. 2016). There are rare cases of CPP progressing to CPC (Dhillon et al. 2013; Jeibmann et al. 2007; Niikawa et al. 1993).

CPCs (WHO Grade III) have frankly malignant features (Fig. 10.4). As opposed to the benign variants, CPCs do not have organized papillary structures. The nuclei are not homogenously round, as in normal choroid plexus. Nuclei are elongated, differ from cell to cell, and may form bizarre, irregular shapes. There is a dramatically increased density or crowding of cells compared to the benign variants. There

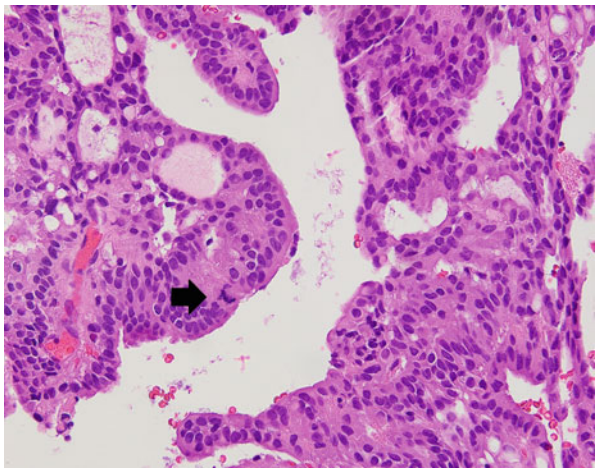

Fig. 10.4 Choroid plexus carcinoma (400× magnification) is a WHO Grade III tumor defined by the presence of several high-grade features, including a high rate of mitoses (arrow), irregularly and heterogeneously shaped nuclei, loss of papillary architecture, and necrosis

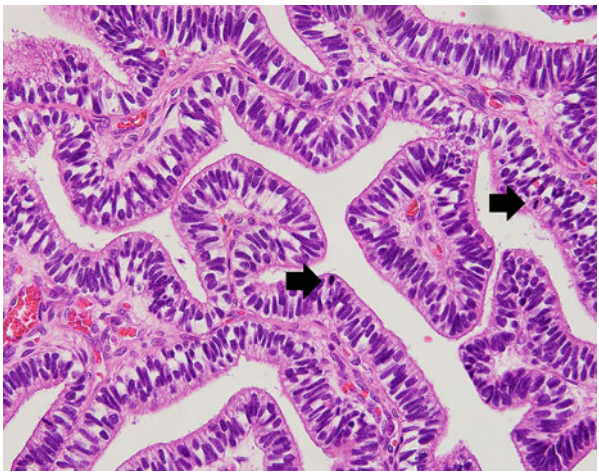

Fig. 10.5 Atypical choroid plexus papilloma (400× magnification) is a WHO Grade II tumor with is defined by a higher amount of mitoses (arrows) than a choroid plexus papilloma, but does not meet the criteria for a choroid plexus carcinoma

is a high mitotic rate (>5 mitoses per 10 high-powered fields); the arrow in Fig. 10.4 indicates a mitotic figure. CPCs are characterized by at least four of five histologic features: high mitotic rage (>5 mitoses per 10 high-powered fields), increased cellularity, nuclear pleomorphism, necrosis, and loss of papillary architecture (Fig. 10.4) (Ellenbogen et al. 1989; Ogiwara et al. 2012; St Clair et al. 1991). Brain invasion is not necessary for the diagnosis of CPC, but it is a common finding (Louis et al. 2016).

In 2007, the WHO Working group recognized an intermediate Grade II entity (Fig. 10.5). This tumor was considered an "atypical" choroid plexus papilloma and is separated from the standard CPP by an increased mitotic rate of (≥2 mitoses/10 high power fields). aCPPs retain a papillary architecture, but the structures are often more complex and irregular than CPPs. The cells show crowding and may have elongated

nuclei. The arrows in Fig. 10.5 indicate mitotic figures. The increased mitotic rate is the defining factor of aCPP compared to CPP, as the other histological factors are variable (Louis et al. 2007). These tumors may have overlapping features with CPCs, without reaching the threshold for a Grade III diagnosis.

The diagnosis of aCPP depends on the patient's age. Patients over 3 years of age with aCPPs have a higher probability of tumor recurrence and an overall worse prognosis compared to patients with CPPs. However, an evaluation of 149 patients in the choroid plexus tumor registry of the International Society of Pediatric Oncology (CPT-SIOP) showed that the clinical outcomes and the progression free survival of children less than 3 years of age was the same in patients with CPP or aCPP (Thomas et al. 2015). Therefore, increased mitotic activity is only considered to be of prognostic value in children over 3 years of age.

10.4.3 Immunohistochemistry

Immunohistochemical staining of a choroid plexus tumor is similar to normal choroid plexus, although CPCs have significant variability (Louis et al. 2016). The normal choroid plexus reacts positively with cytokeratin (CK) stains, particularly CK7. It also reacts with vimentin, S100, and transthyretin (prealbumin). Normal choroid plexus cells also reactive positively for stains directed toward the potassium channel KIR7.1. Stains for epithelial membrane antigen (EMA) and glial fibrillary acidic protein (GFAP) are weak or negative (Louis et al. 2016).

Most CPPs are positive for cytokeratins, vimentin, and podoplanin (Safaee et al. 2013a). KIR7.1 and stanniocalcin-1 are sensitive and specific markers for CPPs (Hasselblatt et al. 2006). CPPs may show any combination of CK7 and 20, but are most commonly CK7 positive and CK20 negative (74%) (Gyure and Morrison 2000). The Ki-67 and mouse intestinal bacteria (MIB-1) indices are also useful for differentiating CPPs from higher grade choroid plexus tumors by defining the mitotic activity (Safaee et al. 2013a).

Aquaporins (AQP) are selective water channel proteins that are integral to human homeostasis and may be integral in cerebrospinal fluid production. Normal choroid plexus heavily expresses AQP1 in the apical portion of cuboidal cells. CPPs also express AQP1, although in a variable, heterogenous degree. The intensity of AQP1 expression in CPPs correlates with the presence of hydrocephalus (Longatti et al. 2006; Paul et al. 2011). However, CPCs do not stain for AQP1.

Immunohistochemistry is an important method to distinguish choroid plexus tumors from other primary or metastatic neoplasms. Choroid plexus tumors may be differentiated from metastatic lesions by their lack of human epithelial antigen (HEA)-125 and Ber-EP4 expression (Safaee et al. 2013a). These are tumor markers sensitive to cancer of the skin, ovarium, colon, prostate, stomach, and lung. Another intraventricular tumor is an ependymoma. Choroid plexus tumors may be differentiated from ependymomas with the tumor markers E-cadherin and neural cell

adhesion marker (NCAM). Choroid plexus tumors are E-cadherin+/NCAM- and ependymomas are E-cadherin-/NCAM+. Tumors of the pineal gland may also present in the same anatomic area as choroid plexus tumors. The lack of NCAM and lack of microtubule-associated protein 2 differentiates choroid plexus tumors from primary tumors of the pineal gland (Safaee et al. 2013a).

10.4.4 Molecular Genetics

The most established genetic connection associated with choroid plexus tumors is alteration of the p53 tumor suppressor gene. Alteration in this gene increases the risk of choroid plexus tumors (Gozali et al. 2012). Patients with Li-Fraumeni syndrome, a hereditary condition with p53 gene mutations, develop many types of neoplasms, including choroid plexus tumors. Mutations in the p53 gene are found in 50% of CPCs and 5% of CPPs (Tabori et al. 2010). Tumors with p53 alterations show increased aggressiveness and patients have a worse prognosis (Merino et al. 2015). Polymorphisms in mouse double minute 2 homolog (MDM2), a negative regulator of p53, cause defects in the tumor suppressor function. Defects in MDM2 are also associated with choroid plexus tumors (Tabori et al. 2010).

"Notch" is another gene associated with choroid plexus tumors. The Notch pathway is a central regulator during neural development, promoting proliferation and inhibiting differentiating of embryonic progenitor cells in the central nervous system (Dang et al. 2006). These mechanisms are parasitized by tumors to promote their own growth and survival. The distribution of Notch proteins differs between normal choroid plexus and tumors. In normal choroid plexus, Notch 1, 2, and 4 are distributed in the cell membrane and cytoplasm. In neoplastic cells, these proteins are found in the nuclei; this enhances their signaling capabilities (Beschorner et al. 2013). Notch 3 has been shown to be instrumental in the formation choroid plexus tumors in experimental mice (Dang et al. 2006). The mechanism through which Notch signaling promotes choroid plexus tumor formation is thought to be through the Sonic Hedgehog (SHH) gene (Li et al. 2016).

Multiple other genes are associated with choroid plexus tumors (Merino et al. 2015; Losi-Guembarovski et al. 2007; Tong et al. 2015). Genes associated with tumorigenesis include: Twist-related protein 1 (TWIST1), Wnt inhibitor factor 1 (WIF1), transmembrane protein Shrew-1 (AJAP1), transient receptor protein, M2 channel (TRPM2), BCL2-associated transcription factor (BCLAF1), and IL-6 signal transducer (IL6ST) (Hasselblatt et al. 2009). Platelet derived growth factor (PDGF) is a known oncogene in multiple tumors, including choroid plexus tumors. PDGF receptors are phosphorylated at abnormally high levels in CPCs (Koos et al. 2009; Nupponen et al. 2008). Other genes that are influential in CPC progression include TAF12, NFYC, and RAD54L (Tong et al. 2015). TAF12 and NFYC are epigenomic regulators; RAD54L plays a role in DNA repair.

10.5 Clinical Treatment

Patients often present with signs and symptoms of hydrocephalus. Hydrocephalus may result from mechanical obstruction of the normal CSF pathways or by hypersecretion of CSF from the tumor (Kahn and Luros 1952). The degree of hydrocephalus is not correlated to the anatomic location, size, or pathology of the tumor (Pencalet et al. 1998; Safaee et al. 2013b). Choroid plexus tumors may produce up to 800 ml of CSF per day, well above the normal physiologic production of approximately 450 ml per day (Pencalet et al. 1998; Eisenberg et al. 1974; Ghatak and McWhorter 1976). Approximately 25–50% of all patients with choroid plexus tumors will require permanent CSF diversion (Ogiwara et al. 2012; Pencalet et al. 1998; Tacconi et al. 1996). Complete surgical resection of the tumor reduces the overproduction of CSF and will cure hydrocephalus in approximately 70–80% of tumors. However, 20–30% of patients will still require treatment of hydrocephalus despite tumor removal (Bettegowda et al. 2012). Possible reasons for hydrocephalus after tumor excision include arachnoiditis, hemorrhage, elevated CSF protein, debris from the tumor, or mechanical obstruction of the cerebral aqueduct. Pre-operative endovascular embolization of feeding arteries reduces the production of CSF, however this alone does not alter the overall need for CSF diversion (Haliasos et al. 2013a).

The treatment of choice for choroid plexus tumors is surgical resection. Gross total resection (GTR) of the tumor is the most important factor determining the risk of recurrence and the rate of long-term survival (Wolff et al. 2002; Bettegowda et al. 2012; Bahar et al. 2017; Koh et al. 2014; Krishnan et al. 2004).

Complete resection of CPPs is often curative (McGirr et al. 1988; Bostrom et al. 2011). The 10-year survival of patients with a GTR of CPPs approaches 100% (McGirr et al. 1988; Ogiwara et al. 2012; Pencalet et al. 1998; Safaee et al. 2013b; Bettegowda et al. 2012; Menon et al. 2010). Patients do not require adjuvant therapy after surgical resection. The overall survival in patients with a subtotal resection remains positive. Patients with a small residual should be observed closely, but do not require radiation or chemotherapy. CPPs are often quite indolent, and residual tumor has been observed without signs of growth for years. A second surgery is indicated if residual tumor grows. Adjuvant therapy is considered for inoperable lesions that demonstrate clear signs of growth or malignancy (McGirr et al. 1988; Safaee et al. 2013b; Krishnan et al. 2004; Menon et al. 2010).

Complete resection of aCPPs may be curative (Koh et al. 2014). However, recurrences are more common in aCPPs than CPPs. Jeibmann reported a series of patients with gross total resection of choroid plexus tumors. Six of 103 (6%) patients with CPPs suffered a recurrence. Six of 21 (29%) of patients with aCPPs suffered a recurrence. The difference was statistically significant (Jeibmann et al. 2007). In two of the patients in this series, the pathology of the recurrent tumor had progressed to CPC.

The survival of patients with CPCs is significantly worse than those with CPPs. In a large meta-analysis performed in 2002 by Wolff et al., the 5- and 10- year survival

for CPPs was 81% and 77% respectively. For CPCs, the survival dropped to 41% and 35% respectively (Wolff et al. 2002). Similarly, Pencalet et al. reported a 5-year survival of 100% in patients with CPPs and 40% in patients with CPCs in a single institution experience of 38 tumors (Pencalet et al. 1998). Overall, the 5-year survival of patients with CPC ranges from 26–41% (Lam et al. 2013). Choroid plexus carcinomas are approximately 20 times more likely to recur and metastasize compared to CPPs (Bettegowda et al. 2012). Gross total resection significantly improves survival in patients with CPCs (Ogiwara et al. 2012; Gupta 2003; Sun et al. 2014b; Wolff et al. 1999). In a population based study using data from the SEER (surveillance, epidemiology, and end results) database, the 5-year survival of patients with a gross total resection of a CPC was 70.9%, compared to 35.9% after subtotal resection (Lam et al. 2013). GTR may be technically difficult due to brain invasion or anatomic features. In older series, GTR was achieved in less than 50% of patients (Boyd and Steinbok 1987; Gupta 2003; Berger et al. 1998; Chow et al. 1999; Hawkins 3rd 1980). If tumor resection is incomplete, a "second-look" surgery is beneficial. In a series reported by Sun et al., the 2 year survival of patients with CPC and a second resection was 69%, compared to 30% in patients without a second surgery (Sun et al. 2014a).

CPCs are generally treated with adjuvant therapy after surgery. Chemotherapy improves survival. Chemotherapy is of particular importance in children under three years of age, as radiation may be devastating to the developing brain. Multiple chemotherapeutic agents have been employed, including carboplatin, bevacizumab, vincristine, etoposide, and cyclophosphamide. Due to the rarity of these tumors, a large scale, randomized trial has not been performed. However, platinum-based therapies and etoposide are most often used based on the established result in other pediatric brain tumors (Mallick et al. 2017). Etoposide may be the most efficacious single agent (Mallick et al. 2017). There are a few encouraging case reports of high-dose chemotherapy and autologous stem cell transplant in younger children (Bostrom et al. 2011).

The use of radiotherapy is controversial. There are studies that indicate a better overall survival rate in patients treated with craniospinal radiation (Wolff et al. 1999; Mazloom et al. 2010). Other reports failed to find any survival benefit with radiotherapy, including an analysis of the SEER database (Lam et al. 2013; Gupta 2003; Packer et al. 1992; Sampath et al. 2008).

While gross total resection is key to treatment, surgery may be technically challenging. Choroid plexus tumors may be extremely vascular. The major cause of surgical morbidity or mortality in children is perioperative blood loss (St Clair et al. 1991; Pencalet et al. 1998; Due-Tonnessen et al. 2001). Older series cite a surgical mortality rate of up to 30% because of hemorrhage (Guidetti and Spallone 1981). The vascular supply for the tumor generally includes a major feeding vessel from the choroidal arteries (Ogiwara et al. 2012). Unfortunately, this vessel is generally in the deepest part of the surgical bed and may not be encountered until the later stages of the surgery.

Modern surgical techniques have improved the feasibility of resection of tumors. The operating microscope and neuroendoscope provide significant improvements in

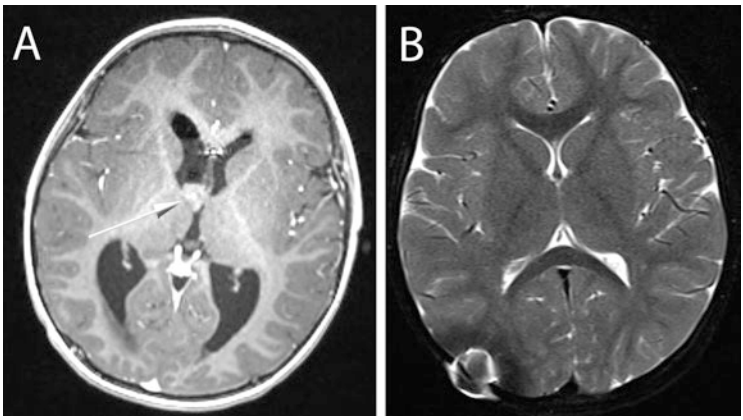

Fig. 10.6 A 35-month old child presented with rapid progression of hydrocephalus. A T1-weighted MRI with gadolinium contrast shows an obstructive lesion at the level of the foramen of Monroe (**a**). This lesion was removed with a right frontal neuroendoscopic approach. The endoscope allowed removal of the lesion with minimal trauma to the surrounding brain. The lesion was a choroid plexus papilloma, WHO Grade I. There is no residual or recurrent tumor at the level of the foramen seen on a follow-up T2 weighted axial MRI one year after surgery (**b**). The child did not receive adjuvant therapy. However, despite complete tumor removal, the child required a cerebrospinal fluid shunt to treat hydrocephalus

visualization of these deep, intraventricular lesions. Figure 10.6a shows a choroid plexus papilloma located at the Foramen of Monro. This tumor was removed through a small, minimally-invasive approach with a neuroendoscope (Fig. 10.6b). In experienced hands, minimally invasive approaches mitigate cortical trauma and intraoperative blood loss. Endovascular embolization may significantly decrease the vascularity of the tumor and also reduce surgical blood loss (Haliasos et al. 2013b). There is a report of tumor regression in a 3-month-old child after embolization alone (Wind et al. 2010).

With the increasing availability of imaging, incidental CPPs may be discovered in patients without symptoms or hydrocephalus. There is no clear evidence to recommend surgery or observation in these patients (Laarakker et al. 2017). The natural history of incidentally discovered choroid plexus tumors is unknown. There are reports of rapid progression of tumors in younger children (Fig. 10.7a, b) (Gorelyshev et al. 2013; Jamjoom et al. 2009). However, there are also reports of very indolent behavior of the residual of subtotally resected tumors. With no clear, scientific evidence, decisions on incidentally found CPPs should be made on a "case-by-case" basis with a thorough discussion of the surgical risk with the patient and the family. The advantage of observation includes the possibility that the tumor will remain indolent and the avoidance of surgical risk. The advantage of surgery is that it may be curative, will provide specimen for pathologic diagnosis, and may avoid subsequent development of symptoms.

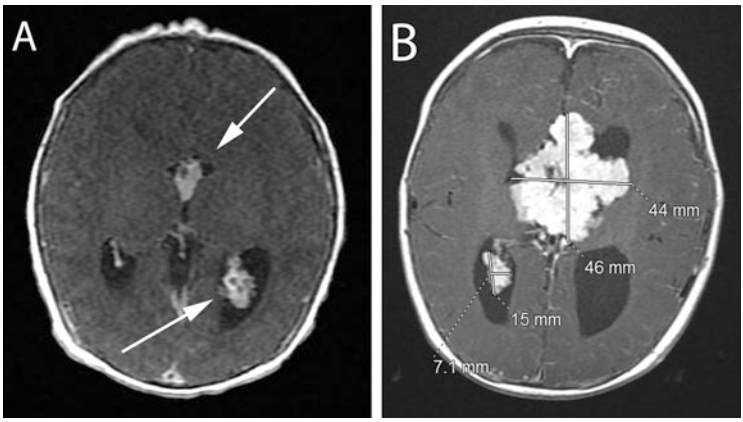

Fig. 10.7 A rapidly progressing multifocal tumor in an infant is shown. (**a**) Axial T1-weighted MRI image with gadolinium contrast in a newborn shows a tumor in the third ventricle and another in the left lateral ventricle. The left ventricular tumor was removed at 3 months of age. By 6 months of age, the third ventricular tumor grew significantly (**b**)

10.6 Conclusions

Choroid plexus tumors may be benign, malignant, or have an intermediate grade. Benign CPPs are the most common, representing 80% of all choroid plexus tumors. The tumors tend to be located within the ventricles and may be very vascular. The tumors are more common in the pediatric population, and are one of the most common brain tumors encountered in children under 1 year of age. Choroid tumors have a very characteristic "cauliflower" appearance on imaging studies. They are often accompanied by hydrocephalus, which may persist despite removal of the tumor. Surgical resection is the treatment of choice; gross total resection improves the outcomes of patients with all three grades of tumor. Adjuvant therapy is reserved for malignant or inoperable tumors. There are encouraging results with chemotherapy for malignant tumors. The role of radiation therapy is controversial. The clinical outcome in patients with CPPs is very good with surgery alone. The long-term survival in patients with CPCs is less encouraging, and multimodal therapy is required.

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