Childhood Brain Tumor Epidemiology: A Brain Tumor Epidemiology Consortium Review

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Abstract

Childhood brain tumors are the most common pediatric solid tumor and include several histologic subtypes. Although progress has been made in improving survival rates for some subtypes, understanding of risk factors for childhood brain tumors remains limited to a few genetic syndromes and ionizing radiation to the head and neck. In this report, we review descriptive and analytical epidemiology childhood brain tumor studies from the past decade and highlight priority areas for future epidemiology investigations and methodological work that is needed to advance our understanding of childhood brain tumor causes. Specifically, we summarize the results of a review of studies published since 2004 that have analyzed incidence and survival in different international regions and that have examined potential genetic, immune system, developmental and birth characteristics, and environmental risk factors. *Cancer Epidemiol Biomarkers Prev; 23(12); 2716–36. ©2014 AACR.*

Introduction

Brain and central nervous system (CNS) tumors are the most common solid tumor and the second leading cause of cancer-related death in individuals 0 to 19 years of age in the United States and Canada (1, 2). The objective of this review is to summarize the descriptive and analytic epidemiology of childhood brain tumors (CBT) with a specific focus on studies from the past decade (since 2004) and to delineate future directions in CBT epidemiology research that are needed for progress in the field. We have included studies published primarily since 2004 pertaining to CBT descriptive and analytical epidemiology. We note that there is no precise definition of CBTs, and the tumor types included vary between studies, which can make them difficult to compare.

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Descriptive Epidemiology

There are >100 different histologic subtypes of CNS tumors with the incidence of each varying by age and histologic subtype. Childhood CNS tumor incidence varies by country from 1.12 to 5.14 cases per 100,000 persons with the highest incidence in the United States (Table 1). CBTs are more common in males, though this varies by histologic type. In the United States, whites and Asians-Pacific Islanders have a higher CBT incidence than blacks and American Indians/Alaska Natives, whereas non-Hispanics have higher incidence than Hispanics. Subtype incidence and survival rates are reviewed below and in Tables 1 and 2.

Case ascertainment methodology, completeness, and standard populations used for age adjustment of rates vary between cancer registries, making it challenging to compare statistics across registries. In addition, registries vary on when they began to include the reporting of benign brain tumors. For example, in the United States, registration of nonmalignant tumors was not required by law and, therefore, limited before 2004. Final confirmation of CNS tumors can also vary by histologic type and by region; even in the United States, some tumors are not microscopically confirmed but are confirmed radiographically. However, across registries, the standard approach is to include both brain tumors and other CNS tumors in all statistics. Therefore, all comparison statistics must be interpreted with these caveats in mind.

Glioma

Gliomas that arise from glial cells are the most common CBT (3). Incidence and survival vary significantly depending on location and histologic type (reviewed below and in Tables 1 and 2).

Table 1. Age-adjusted and age-specific incidence rates[a] per 100,000 persons, by histology, region, and gender

Histologic type	Region (surveillance system[b])	Years	Ages	Overall Rate (95% CI)	0–4 years Rate (95% CI)	5–9 years Rate (95% CI)	10–14 years Rate (95% CI)	15–19 years Rate (95% CI)
All CNS tumors	Europe (128; ACCIS)[c]	1988–1997	0–14	2.99	3.39[d]	3.13	2.43	
	United States (4; CBTRUS)	2006–2010	0–14	5.14 (5.05–5.22)				
	United States (4; CBTRUS)	2006–2010	0–19	5.26 (5.19–5.33)	5.77 (5.63–5.93)	4.89 (4.75–5.03)	4.78 (4.64–4.91)	5.64 (5.5–5.78)
	Japan (129)	1989–2008	0–14	3.61	2.85	4.09	3.84	
	Kuwait (130)[e]	1995–2011	0–19	1.12				
	Denmark, Finland, Norway, and Sweden (131)[c]	1985–2006	0–14	4.20				
	Denmark (132)[e]	1980–1996	0–14	3.95	4.28			
Pilocytic astrocytoma	United States (4; CBTRUS)	2006–2010	0–14	0.90 (0.87–0.93)	0.96[c] (0.90–1.03)	0.91 (0.85–0.97)	0.26 (0.23–0.29)	0.58 (0.54–0.63)
	United States (4; CBTRUS)	2006–2010	0–19	0.82 (0.79–0.85)				
	England (133)[c]	1995–2003	0–14	0.75				
Astrocytoma	Europe (128; ACCIS)[c],[f]	1988–1997	0–14	1.18	1.29[d]	1.26	1.07	
	Japan (129)	1989–2008	0–14	1.32				
	Denmark, Finland, Norway, and Sweden (131)[c]	1985–2006	0–14	1.79				
	Denmark (132)	1980–1996	0–14	1.56	1.64			
Ependymoma/ ependymal tumors[f]	Europe (128; ACCIS)[c]	1988–1997	0–14	0.34	0.54[c]	0.23	0.17	
	United States (4; CBTRUS)	2006–2010	0–14	0.28 (0.26–0.30)				
	United States (4; CBTRUS)[g]	2006–2010	0–19	0.28 (0.26–0.29)	0.43 (0.39–0.48)	0.22 (0.19–0.25)	0.21 (0.18–0.24)	0.25 (0.22–0.29)
	Japan (129)	1989–2008	0–14	0.15				
	Denmark, Finland, Norway, and Sweden (131)[c]	1985–2006	0–14	0.42				
	England (133)[c]	1995–2003	0–14	0.25				
	Denmark (132)[e]	1980–1996	0–14	0.37	0.65			
Embryonal tumors[h],[i]	United States (4; CBTRUS)	2006–2010	0–14	0.80 (0.77–0.84)	1.27 (1.20–1.35)	0.75 (0.70–0.80)	0.41 (0.38–0.46)	0.24 (0.21–0.27)
	United States (4; CBTRUS)	2006–2010	0–19	0.66 (0.64–0.69)				
	Denmark, Finland, Norway, and Sweden (131)[c]	1985–2006	0–14	0.73				
	England (133)	1995–2003	0–14	0.28				
PNET	Austria (14; ABTR)	1996–2006	0–14	0.21 (0.15–0.30)				
	England (133)[c]	1995–2003	0–14	0.08				
Medulloblastoma	Japan (129)	1989–2008	0–14	0.37				
	Austria (14; ABTR)	1996–2006	0–14	0.58 (0.16–0.71)				
	England (133)[c]	1995–2003	0–14	0.20				

(Continued on the following page)

Table 1. Age-adjusted and age-specific incidence rates[a] per 100,000 persons, by histology, region, and gender (Cont'd)

Histologic type	Region (surveillance system[b])	Years	Ages	Overall Rate (95% CI)	0–4 years Rate (95% CI)	5–9 years Rate (95% CI)	10–14 years Rate (95% CI)	15–19 years Rate (95% CI)
ATRT								
	Austria (14; ABTR)	1996–2006	0–14	0.14				
	United States (4; CBTRUS)	2006–2010	0–14	0.11 (0.10–0.12)				
	United States (4; CBTRUS)	2001–2010	0–19	0.07 (0.07–0.08)				

Abbreviations: ABTR, Austrian Brain Tumor Registry; ACCIS, Automated Childhood Cancer Information System; CBTRUS, Central Brain Tumor Registry of the United States; CPBTC, Canadian Paediatric Brain Tumour Consortium.

[a]Rates are adjusted to population of region unless specified otherwise.

[b]Differences in rates by region can be affected by differences in reporting practices and statistical methods of adjustment. For this reason, sources of data and differences in standard populations used for adjustment are provided.

[c]Adjusted to world standard population.

[d]Incidence rate is for ages 1 to 4.

[e]Crude rates.

[f]International Classification of Childhood Cancer (ICCC) group IIIa, based on the International Classification of Diseases for Oncology, 3rd Edition (133).

[g]Defined using the CBTRUS Brain and Central Nervous System Tumor Histology Groupings, based on *2007 WHO Classification of Tumours of the Central Nervous System* (9).

[h]ICCC group IIIb.

[i]Includes PNET, medulloblastoma, and ATRT.

Pilocytic astrocytoma. Pilocytic astrocytoma [World Health Organization (WHO) grade 1] is one of the most common CBTs, representing approximately 17% of all CNS tumors in 0- to 14-year-olds (4). Incidence rates in population-based analyses range from 0.74 to 0.9 cases per 100,000 persons (Table 1). These tumors are usually non-malignant, although some progress to higher-grade tumors (5, 6). Pilocytic astrocytomas have a high overall 10-year survival rate at >96% (4).

Brain stem glioma. Brain stem tumors represent approximately 10% of all pediatric CNS tumors with the most common being diffuse intrinsic pontine glioma (DIPG; ref. 7). DIPG prognosis is dismal with >90% of cases dying within 2 years of diagnosis (8). These tumors are rarely biopsied, and as a result, their true incidence from cancer registry datasets is difficult to assess (8).

All other glioma. Other glioma types are less common in children. Diffuse astrocytomas (WHO grade II) account for approximately 5% of all tumors in children ages 0 to 14 years, with a U.S. incidence rate of 0.28/100,000 (Table 1; ref. 4). High-grade astrocytomas (WHO grades III and IV) are less common, with incidence rates of 0.08 for anaplastic astrocytoma and 0.14 for glioblastoma (4).

Embryonal tumors

Embryonal tumors are theorized to develop in embryonic cells remaining in the CNS after birth. There are three major embryonal tumor types with distinct differences in age at diagnosis and survival: primitive neuroectodermal tumor (PNET), medulloblastoma, and atypical teratoid/rhabdoid tumor (ATRT; ref. 9). Overall embryonal tumor incidence ranged from 0.28 to 0.80 cases per 100,000 children ages 0 to 14 years (Table 1) with a 10-year relative survival rate of 55.5% (Table 2; ref. 4).

Primitive neuroectodermal tumor. Average annual age-adjusted incidence rates for PNET ranged from 0.08 to 0.21 cases per 100,000 children. PNET survival improves with increasing age with U.S. population data from 2001 to 2006 showing 1-year survival rates of 31%, 88%, and 95% for children ages 0 to 1, 1 to 9, and 10 to 19 years, respectively (10). On the basis of the 1993 WHO criteria, histologically similar tumors that are classified as PNETs and medulloblastomas when they occur supratentorially and infratentorially, respectively (11). Before this, tumors were considered PNETs regardless of tumor location.

Medulloblastoma. Medulloblastomas are the most common embryonal tumors with average annual age-adjusted incidence rates ranging from 0.20 to 0.58 cases per 100,000 persons. An analysis of U.S. population data from 2001 to 2006 reported 1-year survival rates of 52%, 90%, and 92% for children ages 0 to 1, 1 to 9, and 10 to 19 years, respectively (10). Molecular analysis has identified four distinct medulloblastoma subtypes that correlate strongly with survival (12). No population-based studies of subtype-specific survival have been reported, but in an international meta-analysis, children with WNT tumors had a 95% 10-year overall survival. Children with SHH

Table 2. Survival rates by histologic type and region

Histologic type	Region	Surveillance system	Years	Ages	1 year Rate (95% CI)	5 years Rate (95% CI)	10 years Rate (95% CI)
All CNS tumors	Europe (128)	ACCIS	1988–1997	0–14		91 (60–62)	
	United States (4)	CBTRUS	2006–2010	0–14	85.2 (84.4–86)	72.3 (71.2–73.3)	68.2 (66.9–69.4)
	Sweden (135)		1984–2005	0–14		76	72
Ependymoma[a]	Europe (128)	ACCIS	1988–1997	0–14		53 (49–57)	
	United States (4)[b]	CBTRUS	1995–2010	0–14	93.6 (91.3–95.4)	72.2 (67.9–76.1)	62.8 (57.5–67.7)
	Sweden (135)		1984–2005	0–14		72	66
Astrocytoma[c]	Europe (128)	ACCIS	1988–1997	0–14		75 (73–76)	
	Sweden (135)		1984–2005	0–14		84	82
Pilocytic astrocytoma	United States (4)	CBTRUS	2006–2010	0–14	98.7 (98.1–99.1)	97.2 (96.3–98.0)	96.2 (94.9–97.2)
Embryonal tumors[d]	United States (4)	CBTRUS	1995–2010	0–14	79.9 (77.9–81.7)	62.1 (59.6–64.5)	55.5 (52.7–58.3)
PNET	Europe (128)[e]	ACCIS	1988–1997	0–14		49 (46–51)	
	United States (4)	CBTRUS	1995–2010	All ages	76.4 (72.9–79.6)	49.5 (45.3–53.6)	42.8 (38.4–47.2)
	United States (10)	SEER	2001–2006	<1	31 (9–58)	14 (2–39)	
	United States (10)	SEER	2001–2006	1–9	88 (81–93)	64 (54–72)	
	United States (10)	SEER	2001–2006	10–19	94 (82–98)	57 (41–70)	
	Sweden (135)		1984–2005	0–14		47	41
Medulloblastoma	United States (4)	CBTRUS	1995–2010	All ages	88.2 (86.5–89.7)	71.1 (68.5–73.5)	62.8 (59.7–65.8)
	United States (10)	SEER	2001–2006	<1	52 (30–70)	42 (22–61)	
	United States (10)	SEER	2001–2006	1–9	90 (86–93)	69 (58–78)	
	United States (10)	SEER	2001–2006	10–19	92 (85–96)	69 (58–78)	
	Sweden (135)		1984–2005	0–14		63	55
ATRT	United States (4)	CBTRUS	1995–2010	All ages	48.1 (40.3–55.5)	28.0 (20.7–35.7)	26.2 (18.8–34.3)

Abbreviations: ACCIS, Automated Childhood Cancer Information System; CBTRUS, Central Brain Tumor Registry of the United States; SEER, Surveillance, Epidemiology, and End Results.

[a]International Classification of Childhood Cancer (ICCC) group IIIa, based on the International Classification of Diseases for Oncology, 3rd Edition (134).

[b]Defined using the CBTRUS Brain and Central Nervous System Tumor Histology Groupings, based on *2007 WHO Classification of Tumours of the Central Nervous System* (9).

[c]ICCC group IIIb.

[d]Includes PNET, medulloblastoma, and ATRT.

[e]ICCC group IIIc.

tumors, group 3, and large cell anaplastic tumors had 51%, 50%, and 32% 10-year survival, respectively (13).

Atypical teratoid/rhabdoid tumor. ATRT is a rare embryonal tumor that most commonly occurs in children <3 years old. Average annual age-adjusted incidence rates range from 0.07 to 0.14 per 100,000 persons (14, 15). Prognosis is generally poor, though survival increases with age (14–18). Overall, median survival is usually between 6 and 18 months (16, 18–20). Most analyses show that ATRTs are more common in males (15, 16, 21) and among whites (15, 22). A systematic diagnostic approach for ATRT was not common until 2005; before that, these tumors were frequently misclassified, mostly as medulloblastomas or PNET (14).

Analytic Epidemiology

Genetic factors

Cancer syndromes. Established familial cancer syndromes (*gene*) that increase brain tumor susceptibility

include neurofibromatosis type 1 (*NF1*), neurofibromatosis type 2 (*NF2*), tuberous sclerosis (*TSC1* or *TSC2*), Li–Fraumeni (*TP53* or *CHEK2*), nevoid basal cell carcinoma (*PTCH*), Turcot (*APC*), Cowden (*PTEN*), hereditary retinoblastoma (*RB1*), and Rubinstein–Taybi (*CREBBP*; refs. 23–26).

Family history. Findings from studies of CBT risk among family members vary substantially. A 2008 review (27) including publications as early as 1959 reported that although most studies observed positive associations specific to brain tumors, there was borderline statistical evidence for an increased risk. Siblings of childhood CNS cancer cases consistently showed increased risks of developing a childhood CNS tumor, with a higher risk seen if both children had medulloblastoma or PNET diagnoses. Risk was also reported to be higher among relatives if the index child was diagnosed at ≤4 years old. Children also had an increased risk of developing a nervous system tumor if a parent also had this tumor type. The SEARCH

international brain tumor case–control study, which included 1,200 CBT cases and 2,218 controls from Australia, Canada, France, Israel, Italy, Spain, and the United States, reported no significant associations between CBTs and brain tumor history in close relatives, with ORs of 0.8 [95% confidence interval (CI), 0.5–1.3], 1.3 (95% CI, 0.7–2.3), and 1.1 (95% CI, 0.6–1.9) for astroglial ($n = 620$), PNETs ($n = 244$), and other CBT ($n = 324$) subtypes, respectively (28).

Parental age. Parental age at birth may serve as a marker for inherited somatic changes in aging parental germlines. Hemminki and colleagues (29) previously reported that offspring of older fathers (>40 years at the child's birth) were at increased CBT risk with no maternal age effect in a cohort study that included 1,617 CBT cases diagnosed at ages 0 to 14 years. A more recent Swedish analysis (30) of CNS tumors diagnosed in 0- to 4-year-olds ($n = 977$) indicated higher risks associated with paternal age >40 years after maternal age adjustment [incidence rate ratio (IRR) = 1.69; 95% CI, 1.21–2.35], particularly for astrocytoma. In contrast, Johnson and colleagues (31) reported an increased childhood CNS tumor risk in association with maternal age after paternal age adjustment in a U.S. multistate record linkage study including >3,500 cases ($OR_{per\ 5-year\ age\ increase} = 1.08$; 95% CI, 1.03–1.14). Only astrocytomas and ependymomas were associated with an increased risk. The authors also reported stronger IRRs for children diagnosed at younger ages.

Maternal genetic effects. Recent research has addressed the role of maternal genetic variation in genes that may influence the *in utero* environment. In spite of the potential importance of this mechanism in the etiology of CBTs, few assessments of maternal genetic effects have been performed. To our knowledge, there is only one small report that used a case parent triad study design (32) of the role of maternal variation in xenobiotic detoxification genes and the risk of childhood medulloblastoma (33), where it was reported that the maternal *EPHX1* rs1051740 genotype was associated with medulloblastoma risk (RR, 3.26; 95% CI, 1.12–9.53). Larger studies are needed to explore the role of maternal genetic effects in CBT susceptibility.

Immune system

Allergic conditions (allergies, asthma, and eczema). Studies consistently suggest inverse associations between adult gliomas and allergic conditions (34). In children, a 2008 U.K. study including 575 cases diagnosed at <15 years of age and 6,292 controls indicated that maternally reported asthma decreased CNS tumor risk (OR, 0.75; 95% CI, 0.58–0.97), particularly for medulloblastoma/PNETs (OR, 0.43; 95% CI, 0.23–81). However, this result was not confirmed in a participant subset for whom medical records were available (OR, 1.20; 95% CI, 0.74–1.94), which could be due to the diagnosis not being present or not being recorded (35). CNS tumors were not associated with eczema (OR, 0.94; 95% CI, 0.74–1.18), but there was a significant inverse association for children with both

asthma and eczema (OR, 0.48; 95% CI, 0.28–0.81; ref. 36). A study of 272 matched case–control pairs reported an inverse association between CBTs diagnosed between 0 and 15 years old and asthma (OR, 0.55; 95% CI, 0.33–0.93), which was stronger for ependymoma (OR, 0.15; 95% CI, 0.18–1.21). No association with eczema was found. Overall, CNS tumor risk was increased with use of asthma controllers (e.g., inhaled corticosteroids; OR, 2.55; 95% CI, 0.79–8.20) or asthma relievers (e.g., beta agonists; OR, 1.62; 95% CI, 0.57–4.63; ref. 37). Finally, CEFALO, a study conducted in Denmark, Norway, Sweden, and Switzerland that included 352 CBT cases diagnosed from 7 to 19 years and 646 controls, found no association with any atopic condition (asthma, wheezing, eczema, allergic rhinitis; OR, 1.03; 95% CI, 0.70–1.34) and some evidence for reverse causality; an inverse association between CBTs and having a current (OR, 0.76; 95% CI, 0.53–1.11) but not past (OR, 1.22; 95% CI, 0.86–1.74) atopic condition was found (38). Altogether, allergic conditions may be a protective factor for CBT development, but further research is needed.

Markers of infectious exposures. Studies, before 2004, of markers of infection and CBT risk have yielded mixed results (39–41). More recently, higher risks of CBTs among first-born children versus those with higher birth order and lower risks among those who attended daycare as an infant have been reported. Altieri and colleagues (42) compared the incidence of brain tumors in the Swedish Cancer Registry based on the number of total siblings, older siblings, and younger siblings. When compared with cases diagnosed at <15 years old with no siblings, the relative risk (RR) for cases with ≥3 younger siblings was increased for astrocytoma (RR, 1.34), medulloblastoma (RR, 2.30), ependymoma (RR, 2.61), and meningioma (RR, 3.71). Shaw and colleagues (43) reported that CBT risk was elevated for having siblings (OR, 1.4; 95% CI, 0.9–2.3) and being at least second born (OR, 1.7; 95% CI, 1.2–2.4).

Several studies suggest infectious exposures during older childhood increase brain tumor risk, whereas earlier infections reduce brain tumor risk. Harding and colleagues (44) reported that children who had no social contact with other infants in the first year of life displayed an increased CNS tumor risk versus those who had such early exposures (OR, 1.37; 95% CI, 1.08–1.75), particularly among medulloblastoma cases (OR, 1.78; 95% CI, 1.12–2.83). In addition, children who attended informal (OR, 0.86; 95% CI, 0.68–1.09) or formal (OR, 0.93; 95% CI, 0.68–1.26) daycare showed slightly reduced risks versus those reporting social contact only. Shaw and colleagues (43) reported that CBT risk was reduced for subjects who attended daycare for >1 year or were breastfed, whereas Harding and colleagues (45) found no association between breastfeeding and CBTs (OR, 1.01; 95% CI, 0.85–1.21). Most recently, Andersen and colleagues (46) reported that glioma (OR, 2.93; 95% CI, 1.57–5.50) and embryonal tumor (OR, 4.21; 95% CI, 1.24–14.30) cases had more frequent sick days with infections in the first 6 years of life versus controls. However, the timing of infections in

relation to the first year of life versus later in childhood was not evaluated. One common observation from these studies is that level of risk often varies by age at diagnosis and tumor type.

Developmental and birth characteristics

Congenital anomalies. Congenital anomalies (CA) and birth characteristics have been examined as putative risk factors for pediatric CNS tumors (47–49). Among large studies, 45,200 children with CAs were identified in the Canadian Congenital Anomalies Surveillance System and matched to 45,200 children without CAs identified through the Ontario Birth Certificate File. The Ontario Cancer Registry was then used to identify 212 newly diagnosed cancers in the matched cohorts. The authors observed a 2.5-fold increased CNS cancer risk in association with CAs that was stronger for children <1 year old (5.5-fold greater risk). Those with nervous system anomalies had an approximate 6-fold increased rate of primary CNS tumors (50).

Using two population-based national birth registries in Sweden and Norway, Bjorge and colleagues (51) linked birth and cancer registry data to examine risk of multiple pediatric cancer types in association with birth defects. Specifically, children with nervous system malformations were at elevated risk of CNS cancers in both countries, particularly Norway.

Fisher and colleagues (52) linked data from the California Cancer Registry (CCR) to the Birth Defects Monitoring System for the period of 1988 to 2004 among children ages 0 to 14 years. There were 4,869 children identified with cancer, among whom 222 had a major birth defect. The authors reported a 1.87-fold (95% CI, 0.6–5.79) and 1.80-fold (95% CI, 1.28–2.53) elevated risks of CNS tumors among children with and without nonchromosomal and chromosomal anomalies, respectively.

A second study linking the CCR to California birth certificates examined birth anomalies and CNS tumor risk among children ages 0 to 14 years old between 1988 and 2006 (53). In this study, 4,560 newly diagnosed CNS tumors were identified of which 3,733 cases (82%) could be linked to the birth registry. Cases were then individually matched to four controls ($n = 14,932$). Medulloblastomas and PNETs were more elevated in children with birth defects, with age-stratified analyses revealing stronger risks for younger children (OR, 1.7; 95% CI, 1.12–2.57 and OR, 2.9; 95% CI, 1.68–5.05 for children <2 and <1 year(s) old, respectively). This study was limited by the inability to capture birth defect information after hospital discharge.

Birth characteristics. In one of the largest studies to date, Bjorge and colleagues (54) conducted a nested case–control study to examine fetal growth in relation to cancer development in Nordic children born between 1967 and 2010 using population-based birth registries. Each case ($n = 17,698$) was matched to 10 controls ($n = 172,422$). Both higher birth weight ($RR_{\geq 4,500\ g\ vs.\ 3,000–3,499\ g} = 1.3$;

95% CI, 1.1–1.3) and increasing head circumference ($RR_{39–45\ cm\ vs.\ 33–36\ cm} = 1.7$; 95% CI, 1.2–2.3; P trend < 0.001) were associated with childhood CNS cancer risk. In a similar but smaller study including the same four Nordic nations, Schmidt and colleagues (55) conducted a nested case–control study to examine the impact of fetal growth (including birth weight) on CNS tumor risk among children ages 0 to 14 years who were diagnosed with a CNS tumor between 1985 and 2006. This study matched 3,443 CNS cases identified from national cancer registries to 16,169 birth registry controls and found a significant gestational age-adjusted association between birth weight >4,500 g and risk of all CNS (RR, 1.27; 95% CI, 1.03–1.55), and embryonal (RR, 1.8; 95% CI, 1.2–2.8) tumors but not other histologic subtypes.

Milne and colleagues (56) examined the relationship between fetal growth measured as proportion of optimal birth weight or length and CNS tumor development diagnosed between 1980 and 2004 in children ages 0 to 14 years. Among >600,000 live births, 183 pediatric CNS tumors were identified. There were no statistically significant associations between fetal growth factors and CNS tumor development.

Using CCR data to examine birth characteristics and CNS tumor risk in children ages 0 to 14 years old between 1988 and 2006, MacLean and colleagues (57) matched each child with a CNS tumor ($n = 3,733$) to four controls identified through the California birth certificate database, resulting in 14,932 controls. There was an increased CNS cancer risk in the highest weight category (>4,000 g) among high-grade gliomas, whereas among low-grade gliomas, those in the lowest weight category (<2,500 g) appeared to be protected against CNS tumors. This study indicates that separation of CNS subtype is warranted in studies of birth characteristics and CNS tumor risk.

Finally, in a 2008 meta-analysis, eight studies were identified that examined CBT risk in association with birth weight. Data from over 1.7 million children/young adults (0–18 years old) were analyzed, with 4,162 primary diagnoses of astrocytoma, medulloblastoma, or ependymomas combined. Most cases were identified through cancer registries, and the predominant study design was case–control. The authors found that high birth weight (>4,000 g) was predictive of both astrocytoma (OR, 1.38; 95% CI, 1.07–1.79) and medulloblastoma (OR, 1.27; 95% CI, 1.02–1.60), but not ependymomas, which was only examined in few studies (58).

Environmental exposures

Radiation exposure. High-dose radiation to the head and neck for treatment of cancer or other conditions is an established CBT risk factor (59). Radiotherapy for acute lymphoblastic leukemia is associated with a particularly high risk with several studies published in the 1990s (reviewed in ref. 60) showing increased brain tumor risks (gliomas, PNETs) in children who received prophylactic CNS irradiation (usually a cumulative dose of ~25 Gy).

The latency between radiotherapy and subsequent brain tumor development has been estimated at 7 to 9 years with a higher risk for younger children (60). It has also been broadly accepted for several decades that *in utero* diagnostic radiation exposure is associated with a small-to-moderate dose-dependent increase in childhood cancer risk, including brain tumors (61). Recent studies examining ionizing and nonionizing radiation exposure are reviewed briefly below with study details provided in Tables 3 and 4, respectively.

Ionizing radiation   The Childhood Cancer Survivor Study reported that radiation therapy for a first primary cancer (most were leukemia) was associated with a significant 7.1-fold increased risk of a subsequent CNS tumor (62).

A Danish study examined CBT risk associated with neonatal diagnostic X-ray exposure (vs. no exposure) and observed a 2-fold positive nonsignificant association (63). A Swedish study of individuals born between 1975 and 1984 examined the association between medical record–abstracted prenatal X-ray abdominal exposures and CBTs and found no increased risk overall but an almost 2-fold increased risk for PNETs (64). A U.S. study of medulloblastoma/PNETs examined risks associated with maternally reported postnatal diagnostic X-rays and reported no significant associations for head, dental, or any X-ray exposure versus no exposure (65). A U.K. study reported associations between cancers and medical record–abstracted prenatal diagnostic radiation exposure. On the basis of 25 and 41 exposed CBT cases and controls, respectively, no significant association for prenatal or early infancy radiation exposure was observed (66).

Two studies examined childhood/adolescence CT scans and subsequent brain tumor development. A U.K study employing a retrospective cohort study design that included 176,587 CT scan–exposed individuals reported increased risks of subsequent brain tumor development for the exposed group (67). An Australian study, that included approximately 11 million individuals, also reported significant positive associations between CT scan exposure and brain tumor development with risk generally decreasing with increasing age at first exposure, years since first exposure, and increasing calendar year of first CT scan (68).

An ecological study conducted in Florida in response to an observed excess of childhood brain and other nervous tissue cancers in the 1990s found no evidence to indicate that the observed excess was related to nuclear plant installation in St. Lucie County in 1976 (69).

Nonionizing radiation   Sources of nonionizing radiation that have been studied for their role in CBT risk predominantly include radio frequency/microwave (e.g., cell phones, AM and FM radio, televisions, and microwaves) and extremely low frequency magnetic fields (ELF-MF; e.g., power lines and electrical wiring) that are classified as possibly carcinogenic by the International Agency for Cancer Research (70). Studies have shown no significant associations between nonionizing radiation exposure and CBTs as summarized briefly below.

A South Korean case–control study examined associations between residential AM-radio transmission exposures and CBTs. No significant associations were observed by residential distance to the AM-radio transmitter or for estimated radio-frequency radiation exposure (mV/m) for the fourth versus first quartile (71).

A 2008 meta-analysis that examined associations between residential magnetic field exposure and CBTs reported no significant associations in a number of different analyses (72).

Kheifets and colleagues (73) conducted a pooled analysis of 10 U.S. and European studies and found no evidence for an association between ELF-MFs and CBTs.

A U.K. registry-based case–control study that examined maternal radio-frequency exposure from macrocell cellular phone base stations (masts) and mast proximity during pregnancy and offspring CBT risk reported no association for mother's exposure to masts during early pregnancy or for modeled power density birth address (74).

CBTs and cellular phone use in 7- to 19-year-olds were examined in a European multicenter case–control study (CEFALO); the authors reported no significant association between CBTs and regular cellular phone use versus nonuse (75).

Maternal medical conditions and exposures.   *Medications*   Medications containing amides or amines (e.g., barbiturates, antiepileptics, and antihistamines) may be converted to carcinogenic N-nitroso compounds (NOCs including N-nitrosamines and N-nitrosoamides) upon ingestion through reaction with dietary nitrate in the stomach. Two studies before 2004 did not find statistical evidence for an association between maternal exposure to nitrosable drugs and offspring CBTs (76, 77). Likewise, a large study published in 2006 that included 1,218 CBT cases and 1,218 controls found little support for an association between CBTs and medications containing amines or amides (OR, 1.01; 95% CI, 0.82–1.24) overall or for astroglial (OR, 1.01; 95% CI, 0.78–1.31), PNET (OR, 1.09; 95% CI, 0.75–1.60), or other glial (OR, 1.01; 95% CI, 0.71–1.44) subtypes. No significant associations were found when data were analyzed by age group ($\leq$5 vs. >5 years) or class of drugs (barbituates, antiepileptics, antihistamines, neurally active drugs, diuretics, sex hormones, or antiemetics; ref. 78).

A German case–control study of 399 CNS cases diagnosed between 1992 and 1994 and 2,057 controls evaluated associations between maternally reported medications and CBTs and found no significant associations between CNS tumors and diuretics/antihypertensives (OR, 1.65; 95% CI, 0.73–3.74), "pain relievers" (OR, 1.0; 95% CI, 0.6–1.67), antinauseants or antiemetics (OR, 1.15; 95% CI, 0.68–1.96), or cold medications (OR, 0.81; 95% CI, 0.55–1.21). The authors also reported ORs of 1.23 (95% CI, 0.71–2.12) and 0.92 (95% CI, 0.68–1.24) for associations between offspring CNS tumors and high blood pressure/edema

Table 3. Review of recent studies addressing ionizing radiation–related risks and CBTs

Study design/population	Subject number, radiation measurement method	Radiation indicator	RR (95% CI)	Comment	Ref.
Cohort study of ≥5 years survivors of childhood cancer diagnosed between 1970 and 1986 in the United States and Canada.	166 CNS cases among 14,361 cohort members Medical record abstraction	Therapeutic radiation only for first primary childhood cancer vs. no exposure	OR, 7.07 (2.76–18.1)[a]	Both glioma and meningioma risks were increased with a shorter interval following exposure for glioma vs. meningioma diagnoses. CBT diagnoses were not specifically reported.	(62)
Danish nested case–control study in children with an immaturity diagnosis born from 1977 to 1988. CBT cases were diagnosed from 0 to 19 years. Controls were randomly selected from the base cohort.	25 cases, 43 controls Medical record abstraction	Any newborn diagnostic X-ray exposure vs. none	OR, 2.2 (0.6–8.8)[b]		(63)
Swedish registry linkage study of prenatal X-rays and CBTs. Subjects were born from 1975 to 1984. CBT cases diagnosed from 0 to 14 years were identified in the cancer registry. Controls were randomly selected from the Medical Birth Registrar matched to cases on sex and birth year.	512 CBT cases, 524 controls Medical record abstraction	Any prenatal abdominal X-rays vs. none	OR, 1.02 (0.64–1.62)[c]	Risk estimates for subtypes: low-grade astrocytomas (OR, 0.72; 95% CI, 0.38–1.42), high-grade astrocytomas (OR, 1.06; 95% CI, 0.39–2.88), PNETs (OR, 1.88; 95% CI, 0.92–3.83), or ependymomas (OR, 1.01; 95% CI, 0.24–2.98)[c]. Risk estimates for nonabdominal prenatal X-ray exposures were not significant.	(64)
Case–control study of medulloblastomas and PNETs diagnosed at 0 to 5 years from 1991 to 1997. Cases and controls were ascertained from the Children's Oncology Group and random digit dialing, respectively. Controls were matched to cases on area code, race, and birth date (±6 months for cases diagnosed at <1 year of age, ±1 year for cases diagnosed at >1 year of age).	318 cases, 318 controls Maternal interview	Head X-ray not due to head injury exposure vs. none	OR, 2.3 (0.91–5.7)[d]		(65)
		Postnatal head X-ray exposure vs. none	OR, 1.2 (0.54–2.5)[d]		
		Postnatal dental X-ray exposure vs. none	OR, 1.2 (0.54–2.5)[d]		
		Any postnatal X-ray exposure vs. none	OR, 1.2 (0.71–2.0)[d]		

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Table 3. Review of recent studies addressing ionizing radiation–related risks and CBTs (Cont'd)

Study design/population	Subject number, radiation measurement method	Radiation indicator	RR (95% CI)	Comment	Ref.
Case–control study of prenatal/early infancy diagnostic radiation exposure in 2,690 childhood cancer cases and 7,858 controls. Cases were from the United Kingdom Childhood Cancer Study (UKCCS). Two controls per case were ascertained from the population registrar matched on sex and date of birth (±1 month). Study subjects were born during 1976 to 1996.	25 exposed CBT cases, 41 exposed controls — Medical record abstraction	Prenatal diagnostic radiation exposure vs. none — Early-infancy diagnostic radiation exposure vs. none	OR, 1.06 (0.64–1.77)[e] — OR, 1.06 (0.64–1.77)[e]	Early-infancy radiation exposure was not significantly associated with CBTs in analyses that considered no latency or a two-year latency period.	(66)
Retrospective U.K. cohort of 176,587 individuals exposed to CT scans during childhood. Brain tumor cases were diagnosed from 6 to 45 years during 1985 to 2008.	135 cases — Paper or film CT records were used to measure exposure and estimate dose	CT scan exposure (mGy) — Cumulative dose ≥50–74 vs. <5 mGy	ERR per mGy = 0.023 (0.01–0.049) — RR, 2.82 (1.33–6.03)	No specific information was provided on CBTs.	(67)
Australian registry linkage study of the Medicare and the cancer registry that included 10.9 million individuals. Brain tumor cases were diagnosed through their early 40s among 10.9 million individuals that included 680,000 CT scan–exposed subjects from 1985 to 2005.	283 cases — Australian Medicare administrative database	Any CT exposure vs. none — Brain CT exposure vs. none — Other CT scan vs. none	IRR, 2.13 (1.88–2.41)[f] — IRR, 2.44 (2.12–2.81)[f] — IRR, 1.51 (1.19–1.91)[f]	The risk decreased with number of years since first exposure and with increasing calendar year of first CT scan for age at exposure age groups 1 to 4 and 5 to 9 years.	(68)
U.S. ecological study conducted in St. Lucie County, Florida. CBT cases diagnosed at ages 0 to 19 years during the 1950 to 2000 period.	13 cases	SMR[g] before (1956–1975) and after (1976–2000)the St. Lucie County nuclear power station installation in 1976 in St. Lucie County compared with two neighboring counties.	SMR_before = 0.87 (0.35–2.20) — SMR_after = 0.96 (0.39–2.06)	SMRs were calculated using general U.S. population mortality rates.	(69)

[a]Adjusted for diagnosis group (leukemia, CNS, other).
[b]Adjusted for gestational age.
[c]Adjusted for maternal age, parity, multiple birth, mother born in a Nordic country, gestational age at birth, mode of delivery, breech position, birth weight, birth head circumference, level of hospital, and hypertension during pregnancy; an unadjusted OR for ependymoma was reported due to the low number of cases.
[d]Adjusted for annual household income >$50,000, mother's education, and age of child at interview.
[e]Adjusted for child sex, age at diagnosis, UKCCS study region, birth weight, maternal age, early-infancy radiation (1-year lag), and early ultrasound scans (1-year lag).
[f]Adjusted for age, sex, year of birth, includes one-year lag period.
[g]Standard mortality ratio.

Table 4. Review of recent studies addressing nonionizing radiation–related risks and CBTs

Study design/population	Subject number, radiation measurement	Radiation indicator	RR (95% CI)	Comments	Ref.
South Korean case–control study of radio-frequency exposure from AM-radio transmitters. CBT cases diagnosed at <15 years. Case and control subjects were ascertained from the South Korean Medical Insurance Data System. Controls with respiratory diseases were matched to cases on age and sex at 1:1 ratio.	956 cases, 3,082 controls	Residential distance to the AM transmitter <2 km vs. >20 km	OR, 1.42 (0.38–5.28)[a]	Radio-frequency radiation exposure was defined as "the highest exposure estimate among all the individual exposure estimates obtained from each transmitter established before the subjects' year of diagnosis."	(71)
	Residential addresses and GIS prediction program to estimate radio-frequency radiation	Estimated radio-frequency radiation exposure (mV/m) fourth vs. first quartile	OR, 0.77 (0.54–1.10)[a]		
Meta-analysis of studies conducted in the United States, Sweden, Taiwan, Denmark, Finland, Norway, United Kingdom, Germany, and Japan that examined residential magnetic field exposure [including distance to overhead power lines, wire codes, calculated magnetic fields, and magnetic field measurements (spot or long-term measurements)] and CBTs.	25–6,605 cases, 57–6,605 controls	Residential distance to power lines <50 m vs. ≥50 m (n = 5 studies)	OR, 0.88 (0.57–1.37)	Several influence analyses did not materially change the results and the funnel plot showed no evidence of publication bias. When considering only studies that reported higher doses (0.3 or 0.4 μT), the combined OR was 1.68 (95% CI, 0.83–3.43). The authors concluded that they could not exclude the possibility of an increased risk at higher doses but for lower doses the analyses provided no evidence for an increased risk of CBTs.	(72)
	Distance to overhead power lines, wire codes, calculated magnetic fields, and measured magnetic fields (spot or long-term measurements)	Calculated magnetic field exposure ≥ 2 μT vs. < 2 μT (n = 4 studies)	OR, 1.13 (0.65–1.95)		
		Long-term measured exposure ≥2 μT vs. < 2 μT, the combined (n = 4 studies)	OR, 1.14 (0.65–2.00)		
		High vs. low wire code current configuration (n = 3 studies)	OR, 1.08 (0.6–1.98)		
		Very high vs. low wire current code configuration (n = 3 studies)	OR, 0.83 (0.51–1.36)		
		Spot measurement ≥2 μT vs. < 2 μT (n = 3 studies)	OR, 1.13 (0.61–2.10)		

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Table 4. Review of recent studies addressing nonionizing radiation–related risks and CBTs (Cont'd)

Study design/population	Subject number, radiation measurement	Radiation indicator	RR (95% CI)	Comments	Ref.
Pooled analysis of 10 studies published in the United States and Europe between 1979 and 2010 examining associations between extremely ELF-MFs and CBTs diagnosed at 0 to 15 years.	7,770 cases, 10,883 controls	0.1–<0.2 mT vs. < 0.1 µT	OR, 0.95 (0.65–1.41)[b]	There was no evidence for dose–response, and the results were consistently weak when subjected to numerous analyses.	(73)
	Various	0.2 mT–<0.4 µT vs. < 0.1 µT	OR, 0.70 (0.40–1.22)[b]		
		>0.4 µT vs. <0.1 µT	OR, 1.14 (0.61–2.13)[b]		
U.K. registry-based case–control study of CBT cases diagnosed 0 to 4 years old from 1999 to 2001 who were ascertained from the National Cancer Registry. Controls were ascertained from the birth registry and matched to cases on sex and birth date.	251 CBT cases, 1,004 controls Three exposures were calculated: (i) distance from residential address at birth to macrocell mobile phone base station, (ii) total power output across all base stations within 700 m of residential address at birth, and (iii) modeled power density for base stations within 1,400 m at residential address at birth.	Distance from nearest base station (>1,071.8 m vs. 0–612.0 m)	OR, 0.94 (0.65–1.36)[c]	Residential birth address served as a proxy for exposure address during pregnancy.	(74)
		Total power output (>4.743 kW vs. 0 kW)	OR, 0.84 (0.56–1.27)[c]		
		Modeled power density (≥−17.6965 vs. −70–26.4659 dBm²)	OR, 0.77 (0.53–1.12)[c]		
Multicenter case–control study (CEFALO) conducted in Denmark, Sweden, Norway, and Switzerland. Cases were diagnosed from 7 to 19 years during 2004–2008. Two controls per case matched on age, sex, and geographical region were ascertained from country population registries.	352 CBT cases, 646 controls Cell phone use ascertained through interviews and records where available	Regular use of cell phones vs. nonuse	OR, 1.36 (0.92–2.02)	In a subgroup analysis of individuals where phone operator data were available, an increased brain tumor risk was observed in association with length of mobile phone subscription but not amount of use.	(75)

[a]Adjusted for residential location, population density, and socioeconomic status of the community of residence.
[b]Adjusted for age, study, and sex.
[c]Adjusted for percentage of population with education to degree level or higher and Carstairs deprivation score.

during pregnancy treated with and without drugs, respectively (79).

A Taiwanese pregnancy cohort study examined maternal use of herbal medicines (Coptidis Rhizoma, An-Tai-Yin, and other herbs) and reported an increased HR for brain tumors in association with Coptidis Rhizoma (HR, 4.79; 95% CI, 1.28–17.91; ref. 80).

A Swedish registry–based linkage study used medical record data to examine associations between maternal medication ascertained from medical records and offspring CBTs from 0 to 14 years. No significant associations were found for alimentary tract medicines (mainly antacids and laxatives), vitamins and iron, folic acid (FA), diuretics, antiinfectives (antifungals, penicillin, antibiotics), analgesics [Aspirin/NSAID, Opioids, Paracetamol (acetaminophen), antiemetics, antihistamines, neuroleptics], antiasthmatics (oral and inhalation therapy). In contrast, maternal antihypertensives (OR, 2.7; 95% CI, 1.1–6.5) were positively associated with offspring CBTs, especially for β-blockers (OR, 5.3; 95% CI, 1.2–24.8; ref. 81).

A German case–control study reported significantly increased risks for CNS tumors overall (OR, 1.56; 95% CI, 1.01–2.40), medulloblastoma (OR, 2.07; 95% CI, 1.03–4.17), and astrocytoma (OR, 2.26; 95% CI, 1.09–4.69), but not ependymoma (OR, 1.23; 95% CI, 0.37–4.13) in association with maternal prenatal antibiotic use. For maternal antibiotic exposure, including the three months before pregnancy through pregnancy, the associations were less strong and not significant for CNS tumors overall (OR, 1.37; 95% CI, 0.92–2.05), medulloblastoma (OR, 1.79; 95% CI, 0.92–3.48), astrocytoma (OR, 1.79; 95% CI, 0.87–3.70), or ependymomas (OR, 0.95; 95% CI, 0.28–3.17; ref. 82).

Maternal antibiotic use during pregnancy was also examined in a Canadian case–control study that included 272 case–control pairs. Cases were diagnosed at <15 years of age from 1980 to 1999. A nonsignificant positive association between CBTs and prenatal antibiotic exposure (OR, 1.7; 95% CI, 0.8–3.6) was reported (43).

Maternal nutrition. *Prenatal vitamins/FA* Relatively consistent evidence from earlier studies for a protective effect of prenatal vitamins on offspring CBT risk (reviewed in ref. 83) has been reported. A 2007 German case–control study (79) reported no significant association between CBTs and maternally reported vitamin, folate, and/or iron supplements (OR, 1.07; 95% CI, 0.85–1.34). A U.S. case–control study of 315 medulloblastomas/PNETs diagnosed from 0 to 5 years old from 1991 to 1997 reported no association for periconception (OR, 1.2; 95% CI, 0.8–2.1) or mid-pregnancy (OR, 1.1; 95% CI, 0.7–1.6) dietary folate intake when comparing the highest with lowest quartile of intake (84). In a later report, the authors reported an OR of 0.7 (95% CI, 0.4–1.0) for preconception multivitamin use. For dietary folate with supplements, the periconception and mid-pregnancy ORs for the highest versus lowest intake quartile category (≥380 μg vs. <267 μg) were 0.5 (95% CI, 0.3–0.9) and 0.3 (95% CI, 0.5–1.3) with a significant trend for increasing periconceptional intake (P = 0.007; ref. 85). A Swedish study reported a nonsignificant inverse

association for FA supplementation (OR, 0.6; 95% CI, 0.3–1.1; ref. 81).

A 2010 case–case study compared maternal FA supplement intake in nervous system tumors (n = 44) versus mesodermal tumor (n = 155) cases diagnosed in children ages 0 to 14 years old during the 2004 to 2006 period. The ORs for ≥400 versus <400 μg/day were 0.34 (95% CI, 0.10–1.06), 0.19 (95% CI, 0.06–0.6), 0.57 (95% CI, 0.33–0.99), and 0.94 (95% CI, 0.79–1.14) for preconceptional, <21 days gestation, <36 days gestations, and any period, respectively. Multivitamin supplementation was also inversely associated with CNS tumors for first (OR, 0.29; 95% CI, 0.09–0.92), second (OR, 0.18; 95% CI, 0.02–1.35), and any (OR, 0.22; 95% CI, 0.07–0.68) trimester intake (86). A 2012 Australian study of 327 CBT cases diagnosed from 0 to 14 years between 2005 and 2010 and 867 controls reported inverse associations during pre-pregnancy for maternal FA supplement intake (OR, 0.68; 95% CI, 0.46–1.01) and FA supplement without iron, vitamins B6, B12, C, or A intake (OR, 0.55; 95% CI, 0.32–0.93). No significant associations were found for FA supplement intake during trimester 1 or 2/3. Associations were also inverse for pre-pregnancy use for low-grade gliomas (LGGs) (n = 109) and medulloblastomas/PNETs (n = 47) for any FA versus no FA supplement use (87).

Finally, two ecological studies reported CBT incidence trends in association with mandatory population FA fortification of grain and cereal products. When CBT incidence before and after fortification (1985–1997 to 1998–2006) was compared in a Canadian study, IRRs for children ages 0 to 4 and 5 to 9 years old of 0.95 (95% CI, 0.75–1.19) and 0.91 (95% CI, 0.73–1.13) were found, respectively (88). A similarly designed U.S. study examined CBT incidence patterns from 1986 to 2008 for children diagnosed between 0 and 4 years old by comparing rates for those who were estimated to be *in utero* before versus after fortification in 1998. On the basis of 573 prefortification and 454 postfortification CBT cases, the authors reported significantly lower incidence rates after fortification versus before for PNETs (IRR, 0.56; 95% CI, 0.37–0.84) and ependymomas (IRR, 0.7; 95% CI, 0.51–0.97) but not other brain tumor types or overall. Trend analyses indicated that the data were consistent with a fortification effect for PNETs but not ependymomas (89).

Dietary NOCs Studies of rodents and non-human primates have provided evidence that maternal intake of dietary NOCs, particularly N-nitrosamides, induces brain tumors in offspring. However, their contribution to human CBTs is less clear. Direct NOC sources include nitrite-cured and smoked meat, fish, cheese, and beer, whereas vegetables containing nitrites that can undergo conversion to NOCs are an indirect NOC source (reviewed in ref. 90). A 2004 meta-analysis that included 1,226 CBT cases and 1,768 controls from seven studies reported a summary RR of 1.68 (95% CI, 1.30–2.17) for the association between CBTs and maternal cured meat intake during pregnancy versus no intake (91). Since 2004, a study of 315 medulloblastoma/PNET cases and 315

controls reported no overall association between maternal prenatal cured meat intake and offspring CBTs; however, maternal high cured meat intake in combination with low vitamin C intake increased risk (OR, 1.5; 95% CI, 1.0–2.3; $P = 0.08$; ref. 85). An international case–control study of 1,218 CBT cases and 2,223 controls diagnosed from ages 0 to 19 years old from 1982 to 1992 reported positive associations with ORs ranging from 1.8 to 2.5 across astrocytoma subtypes (92). Finally, one study of 202 cases and 286 controls examined the association between maternal cured meat consumption and CBTs, which was modified by glutathione S-transferase (GST) genotypes involved in NOC inactivation. Increasing risk with increasing frequency of maternal cured meat consumption in children without *GSTT1* (OR, 1.29; 95% CI, 1.07–1.57) was reported (93). Altogether, a causal connection between maternal intake of NOCs and CBTs is possible; however, other nutrients as well as genetic factors may modify risk.

Parental smoking and alcohol. Alcohol exposure *in utero* is a known toxin to the developing CNS. However, in agreement with earlier studies (94), a recent large case–control study did not support maternal consumption as a risk factor for offspring CBTs (95).

The relation between maternal tobacco exposure and CBTs has been studied previously in case–control studies with no significant associations (96–99). Only one recent prospective Swedish linkage study found an association with maternal smoking for CBTs (benign and malignant tumors, HR, 1.24; 95% CI, 1.01–1.53; ref. 100). A recent study assessed neonatal blood spots from 202 cases for genetic polymorphisms that metabolize tobacco-smoke chemicals and reported that the *EPHX1* H139R polymorphism, one of nine polymorphisms that metabolizes polycyclic aromatic hydrocarbons, had a positive interaction OR for both maternal and paternal smokers with CBTs in offspring (P interaction $= 0.02$ and 0.10; ref. 101).

Parental occupation. *Pesticide exposure.* Although several studies suggest a causal relation between residential pesticide exposure and CBTs (reviewed in 2007, see ref. 102; see also residential pesticides section below), results from studies of parental occupational exposure are less consistent. These inconsistencies could be due to heterogeneous definition of "child" (ranging from 0 to 30 years old), difficulties in separating parental occupational exposure from residential use generic definitions of pesticides (i.e., "pesticides" instead of a specific compound), and inconsistent definitions of exposure time windows.

In a Northern England cancer registry study ($n = 843$ CNS tumors; ages 0–24 years old), no association between likely paternal occupational pesticide exposure (at the time of the child's birth) and childhood CNS tumor risk was found when comparing cases with other cancer controls in contrast to population controls where inverse associations were observed for all CNS tumors (OR, 0.44, 95% CI, 0.31–0.63) and astrocytomas (OR, 0.48; 95% CI, 0.27–0.87). However, the inverse associations disappeared when the results were stratified by urban versus rural residence (103).

In the U.S. Atlantic Coast Childhood Brain Cancer Study, 421 case–control pairs <10 years were analyzed (104). A positive association was observed between paternal exposure to herbicides from both residential and occupational sources in the two years before the child's birth and astrocytoma (OR, 1.8; 95% CI, 1.1–3.1) with no evidence of an increased risk for fungicides or insecticides.

The Australian Study of Childhood Brain Tumors (Aus-CBT) included 256 cases and 819 controls ages 0 to 14 years old. Although the authors concluded that exposure to pesticides in preconception as well as during pregnancy is associated with an increased CBT risk, the evidence was less clear for parental occupational exposure specifically. Only 13 fathers were classified as "exposed" to occupational pesticides in the year before pregnancy (OR, 1.36; 95% CI, 0.66–2.80; ref. 105).

In a meta-analysis of this topic including studies published between 1985 and 2008, there was a significant positive association between CBTs and paternal (OR, 1.40; 95% CI, 1.20–1.62) but not maternal occupational pesticide exposure (106). In a second meta-analysis of studies published between 1974 and 2010, a positive association between parents who had potential prenatal occupational pesticide exposure (including farm/agricultural workers, pesticide applicators, pesticide manufacturers, and others such as gardeners, greenhouse workers, etc.) and offspring brain tumors was reported after combining all case–control (summary OR, 1.30; 95% CI, 1.11–1.53) or cohort (summary rate ratio, 1.53; 95% CI, 1.20–1.95) studies (107).

ELF exposure. Previous studies examining the possible association between parental occupational ELF exposure in different exposure time windows and CBTs are inconsistent (108). A recent U.K. registry-based case–control study of CNS tumors examined associations with likely paternal occupational exposure to the broad category of radiation or electromagnetic fields, applying an occupational exposure matrix to jobs reported on birth certificates (109). No association was observed with all CNS tumors combined or for ependymomas, astrocytomas, PNETs, other gliomas, or other specified intracranial and intraspinal neoplasms.

A 2009 Canadian study of 548 incident CBTs (ages 0–14 years old) and 760 control subjects assessed potential associations with indicators of maternal occupational ELF exposure based on individualized exposure estimates or a job exposure matrix (JEM) applied to job history information collected during interview (110). Positive associations between average ELF exposure ≥90th percentile (0.30 μT) but not cumulative or peak exposure in the two-year period before conception were observed for CBTs overall (OR, 1.4; 95% CI, 1.0–2.1) and astroglial tumors specifically (OR, 1.5; 95% CI, 1.0–2.4). Positive associations between average ELF exposure ≥90th percentile (0.28 μT) during the pregnancy period were also observed for all CBTs (OR, 1.5; 95% CI, 1.1–2.2) and astroglial tumors (OR, 1.6; 95% CI, 1.1–2.5).

A German case–control study of 444 child CNS tumors (0–14 years) from the German Childhood Cancer Registry and 444 controls recruited through resident registration office files examined associations with preconceptional parental occupational exposure to ELF estimated using a JEM applied to lifetime occupational histories collected during interview (111). No clear association was observed with preconceptional paternal occupational ELF exposure >0.2 μT (OR, 1.06; 95% CI, 0.84–1.34) or >1 μT (OR, 1.19; 95% CI, 0.81–1.75). Similarly, no association was observed with preconceptional maternal occupational ELF exposure >0.2 μT (OR, 0.88; 95% CI, 0.58–1.33).

Other parental occupational exposures. In recent analyses, a Taiwanese case–control study including 74 incident brain tumor cases <30 years old and 170 controls reported preliminary results that CBTs were associated with maternal preconceptional occupations for electronic parts and component manufacturing (OR, 11.81; 95% CI, 1.20–116.3) and the textile and garment industry (OR, 7.25, 95% CI, 1.18–31.0; ref. 112). In contrast, analyses of the complete study of 202 CBT cases and 501 controls revealed no associations with parental (paternal or maternal) or personal occupation or industry for brain tumor risk overall, or with glioma specifically, nor with parental exposure to petrochemicals. A complete list of the industries/occupations studies is not included in the article. Selected industries/occupations studied included agriculture, forestry, fishing; electricity, gas, and water; clerks; plant and machine operators and assemblers; construction; and craft and related trades workers (113).

An Australian population-based case–control study examined associations between parental occupational exposure to engine exhausts and brain tumors in children ages 0 to 14 years (114). A total of 306 CBT cases were examined with 950 controls. Estimates of paternal and maternal exposure to diesel, petrol, and other exposures one and two years before birth and the year following birth were inferred based on a decision-rule approach. Significant positive associations for maternal (OR, 2.03; 95% CI, 1.09–3.81) and paternal (OR, 1.38; 95% CI, 1.02–1.86) diesel exhaust exposure any time before birth were observed. Paternal occupational exposures to petrol and other exhausts were also studied; however, no significant association at any time before birth was found (OR, 1.31; 95% CI, 0.92–1.87). No associations between CBTs and occupational exposures to other exhausts were observed. Associations between CBTs and paternal occupational paint exposure were also examined with small positive associations reported for any paternal exposure before the child's birth (OR, 1.32; 95% CI, 0.90–1.92) or in the conception year (OR, 1.25; 95% CI, 0.69–2.28; ref. 115).

In a case–control study of 1,218 CBT cases (0–19 years) and 2,223 controls in seven countries, there was a significant positive association between paternal preconceptional occupational exposure to polycyclic aromatic hydrocarbons (PAH) and risk of all childhood brain (OR, 1.3; 95% CI, 1.1–1.6) and astroglial tumors (OR, 1.4; 95% CI, 1.1–1.7; ref. 116). These results are generally consistent with previous studies on parental occupational PAH exposure (117).

A South Korean study that linked birth to death records from 1995 to 2004 classified parental occupation (listed on birth certificate) as nonmanual (e.g., legislators, professionals, office workers), manual (e.g., skilled agricultural, forestry and fishery workers, craft and affiliated craft workers, device and machine operators), and economically inactive (e.g., students, homemakers, soldiers). For CNS tumors, the HRs for paternal and maternal occupation were not significant (comparing manual and inactive work with nonmanual work). Likewise, when stratified by paternal education level, paternal occupation was not associated with childhood CNS tumors (118).

Lastly, a case–control study of 11,119 CNS tumors diagnosed at ages <15 years from the Great Britain National Registry of Childhood Tumors and 11,039 matched controls from birth records examined potential associations with 33 paternal occupational exposures as well as social class based on job title recorded at birth (119). Significant positive associations were observed with "definite" paternal occupational exposure to animals (OR, 1.40; 95% CI, 1.01–1.96) and lead (OR, 1.18; 95% CI, 1.01–1.39) and a significant inverse association with metal working (oil mists; OR, 0.87; 95% CI, 0.75–0.99). There was also a significant inverse association with paternal social class. Associations were also observed with paternal occupational exposures and specific CNS subtypes; however, they were somewhat sensitive to adjustment for paternal social class.

Residential pesticides. Pesticides are designed to act on the nervous system with some being carcinogenic in animal models (120). Numerous studies have investigated the potential impact of use of household pesticides, pest extermination services on CBT development (117, 121). Overall, these studies suggest positive associations with CBTs. In a meta-analysis, increased CBT risks in association with paternal pesticide use (herbicides, insecticides, and fungicides) in the home or garden during the prenatal (OR, 1.48; 95% CI, 1.22–1.80) or postnatal (OR, 1.66; 95% CI, 1.11–2.49) periods were reported (106). A U.S. case–control study found that parental use of garden or lawn herbicides was significantly associated with childhood astrocytoma (RR, 1.9; 95% CI, 1.2–3.0) for children ages ≤10 years old but not PNETs and medulloblastomas (104). However, another case–control study of PNET/medulloblastoma reported an association with use of pesticides on the lawn during pregnancy (OR, 1.6; 95% CI, 1.0–2.5) or childhood (OR, 1.8; 95% CI, 1.2–2.8) for children ages ≤6 years old at diagnosis (122).

Finally, a case–control study investigated genetic variation in the paraoxonase (*PON1*) gene that is involved in the organophosphorus insecticide metabolism and CBT risk. CBT risk increased with each *PON1-108T* allele the child carried in children exposed to residential insecticides (OR, 2.6; 95% CI, 1.2–5.5) but not among unexposed children (OR, 0.9; 95% CI, 0.5–1.6; ref. 123). Research in an expanded study population also found the association with *PON1* (OR, 1.8; 95% CI, 1.1–3.0) and *FMO1-9536A*

Table 5. Summary of evidence for risk factors for CBTs

Exposure	Comment	Ref.
Strong		
Cancer syndromes	Syndromes include NF1, NF2, tuberous sclerosis, nevoid basal cell carcinoma, Turcot, Cowden, hereditary retinoblastoma, and Rubinstein–Taybi syndrome.	
Ionizing radiation (therapeutic)	Recent studies of childhood cancer survivors continue to support an increased risk in association with therapeutic ionizing radiation treatment.	(59, 62)
Some/suggestive		
Parental age	In support of a large study published in 1999 (>1,600 CBT cases), two recent large studies have also supported a parental age effect, particularly for astrocytoma. However, results are inconsistent with respect to maternal or paternal age.	(29–31)
Birth defects	Four of four large recent studies reported increased risks, particularly for nervous system anomalies.	
Fetal growth	Three recent studies including a meta-analysis of 8 studies reported consistent positive associations between CBTs and higher birth weight categories, whereas one smaller study reported no association of fetal growth measured as proportion of optimal birth weight. In positive studies, there is inconsistency between CBT subtypes. A positive association between head circumference and CBTs was reported in one study.	(54–58)
Ionizing radiation (diagnostic)	Two large studies suggest that CT scans are associated with increased risk of brain tumors. Regarding X-rays, recent evidence suggests that prenatal X-rays of the abdomen have been associated with an increased risk of PNETs but not other types of CBTs. Other X-rays have not been associated with increased risk of CBTs.	(63–68)
FA/prenatal vitamins	Suggestive evidence for an inverse association with CBTs during preconception/early pregnancy from several studies for FA supplements with support from one of two ecological studies that examined CBT incidence before vs. after FA fortification for PNETs.	(79, 81, 84–89)
Maternal dietary NOCs	A meta-analysis of seven studies and two recent case–control studies support a positive association with one study providing evidence for a gene–environment interaction between *GSTT1*, a gene involved in inactivation of NOCs, and maternal consumption of cured meat.	(86, 92–94)
Residential pesticides	A meta-analysis indicated overall positive associations between CBTs and both prenatal and postnatal exposure; however, there is inconsistency between subtypes.	(104, 106, 117, 120–124)
Weak/insufficient		
Maternal genetics	Positive evidence from one study for a role of the *EPHX1* gene involved in xenobiotic detoxification.	(33)
Allergic conditions	Two studies reported consistent reduced risks for maternally reported asthma. One of these studies did not confirm this finding when using medical records to measure asthma history. A third study reported no significant association for atopic conditions (asthma, wheezing, eczema, allergic rhinitis) overall with some evidence for reverse causality.	(33, 36, 37)
Markers of infection	Inconsistent evidence with findings varying based on sex, age at diagnosis, and tumor type.	(39–46)
Maternal medications	Numerous medications have been examined including: diuretics/antihypertensives, pain relievers, antinauseants/antiemetics, cold medications, antacids, laxatives, analgesics, antiasthmatics, antiemetics, and herbal medicines; however, most have been examined only in single studies. A 2006 review indicated no evidence for an association between medications containing amines/amides (barbiturates, antiepileptics, and antihistamines) and CBTs. Two studies provided positive evidence for maternal use of antibiotics and CBT risk. On study indicated that certain herbal medicines were positively associated with CBTs.	(79–82, 136)

(Continued on the following page)

Table 5. Summary of evidence for risk factors for CBTs (Cont'd)

Exposure	Comment	Ref.
Parental occupational exposures	Inconsistent findings that could be due to difficulties in separating parental occupational exposure to pesticides from residential use, generic definitions of pesticides, and inconsistent definitions of time windows of exposure. However, two large meta-analyses support a positive association parental occupational pesticide exposure and offspring CBT risk. For parental occupational ELF exposure, studies are inconsistent. For various other parental occupational exposures (electronic parts, textiles, engine exhausts, petrochemicals, poly aromatic hydrocarbons, paints), there is limited study of the same exposure in different study populations and interpretations are limited due to small study sizes and the need for replication.	(103–107, 109–116, 118, 119)
Little/none		
Family history	Overall, the evidence for a positive association is limited, suggesting that there is not a strong genetic component to most CBT cases.	(27, 28)
Nuclear power plants	One report showed no evidence of an association.	(69)
Nonionizing radiation	There is an overall lack of association observed between several types of nonionizing radiation (residential AM-radio transmission, residential magnetic field exposure, ELF-MF, maternal radio-frequency exposure from cell phone base stations, and cell phone use among 7- to 19-year-olds), but findings not replicated.	(69, 71–75)
Parental alcohol and smoking	No evidence from one recent study of maternal alcohol consumption during pregnancy, in agreement with earlier studies. There is limited evidence for parental smoking as a risk factor for CBT development.	(71–75, 94–101)

(*6) allele (OR, 2.7; 95% CI, 1.2–5.9) among pesticide-exposed children exclusively (124).

Summary and Future Directions

Established CBT risk factors remain limited to ionizing radiation exposure and certain cancer syndromes. However, accumulating evidence suggests relatively consistent support from larger studies and meta-analyses for positive associations between advanced parental age, birth defects, markers of fetal growth, CT scans, maternal dietary NOCs, and residential pesticide exposure (summarized in Table 5 and Fig. 1).

A priority area for future CBT epidemiologic research is the elucidation of both common and rare genetic risk variants that modify risk. Although it is well established that certain genetic syndromes strongly increase CBT risk, no genome-wide association studies that identify common risk variants were published at the time of this review. Identification of common genetic loci as well as potential parental genetic loci that modify CBT risk overall and by subtype will inform CBT biology. Identification of rare germline CBT risk variants through genome sequencing studies will also be an important future research priority.

With the exception of higher doses of ionizing radiation, no definitive environmental risk factors for CBT development exist. However, our review suggests that maternal dietary intake of NOCs, prenatal vitamin supplementation, and residential pesticide exposure may increase risk. Inherent limitations of case–control studies, including small sample sizes, survey measurement error, and selection bias, make it difficult to reach definitive conclusions. Finally, emerging evidence from two administrative data analyses suggests that exposure to CT scans increases brain tumor risk, emphasizing the importance of minimizing radiation exposure from diagnostic tests to the extent possible in children to mitigate cancer risk.

In summary, it is likely that the greatest gains in understanding of CBT etiology in the near future will come from genomic studies that identify genetic factors that modify CBT risk overall and by subtype. It will also be important to identify interactions between genetic and environmental factors and to conduct studies that integrate germline and somatic tumor sequence data to determine how germline variation influences tumor mutation profiles and prognosis. For progress in these areas to occur, a coordinated investment in systematic collection of clinically annotated biospecimens (both tumor and normal) from a large number of CBT cases should be an international priority because cancer is a leading cause of death in children and CBTs have the highest cancer mortality rate among childhood cancers (125). In the United States alone, there are >2,000 children diagnosed each year with brain tumors, representing a substantial population that could be approached for research participation during clinic visits where recruitment success has been shown to be higher (126). A clear need also exists for increased international coordination to make samples available through standardized processes to all researchers with meritorious proposals. A step forward in this direction was recently achieved through funding of a biospecimen bank that will store samples from children diagnosed with cancer at a Children's Oncology Group Institution that

	Demographics	Growth/ development	Germline susceptibility	Immune function	Environmental exposures	Somatic alterations
Reduced risk			Common SNPs Epimutations Maternal genetic effects	**Allergic/ atopic conditions** **Early life exposure to infections**	*In utero* folic acid	
Increased risk	**Race/ethnicity** **Male gender** **Parental age**	Intrauterine growth rate High birthweight Head circumference Congenital anomalies	**Cancer syndromes:** ***NF1*** ***TSC*** ***PTCH*** ***APC*** Common SNPs Maternal genetic effects		**Ionizing radiation** Hazardous air pollutants Pesticides Dietary nitroso compounds	Somatic mutations Epigenetic alterations Tumor micro-environment

Figure 1. Summary of established and suspected risk factors related to CBTs. More established risk factors are listed in bold type. Suggested risk factors that are high priority for validation are listed in nonbold type.

includes 220 centers in North America, Saudia Arabia, Australia, New Zealand, and Europe (127).

Disclosure of Potential Conflicts of Interest

Jennifer Cullen is Director, Epidemiologic Research, Center for Prostate Disease Research. No potential conflicts of interest were disclosed by the other authors.

References

1. Kaderali Z, Lamberti-Pasculli M, Rutka JT. The changing epidemiology of paediatric brain tumours: a review from the Hospital for Sick Children. Childs Nerv Syst 2009;25:787–93.
2. Siegel R, Naishadham D, Jemal A. Cancer statistics, 2013. CA Cancer J Clin 2013;63:11–30.
3. Bauchet L, Rigau V, Mathieu-Daude H, Fabbro-Peray P, Palenzuela G, Figarella-Branger D, et al. Clinical epidemiology for childhood primary central nervous system tumors. J Neuro Oncol 2009;92:87–98.
4. Ostrom QT, Gittleman H, Farah P, Ondracek A, Chen Y, Wolinsky Y, et al. CBTRUS statistical report: primary brain and central nervous system tumors diagnosed in the United States in 2006–2010. Neuro Oncol 2013;15 Suppl 2:ii1–56.
5. Stokland T, Liu JF, Ironside JW, Ellison DW, Taylor R, Robinson KJ, et al. A multivariate analysis of factors determining tumor progression in childhood low-grade glioma: a population-based cohort study (CCLG CNS9702). Neuro Oncol 2010;12:1257–68.
6. Fisher PG, Tihan T, Goldthwaite PT, Wharam MD, Carson BS, Weingart JD, et al. Outcome analysis of childhood low-grade astrocytomas. Pediatr Blood Cancer 2008;51:245–50.
7. Freeman CR, Farmer JP. Pediatric brain stem gliomas: a review. Int J Radiat Oncol Biol Phys 1998;40:265–71.
8. Hargrave D, Bartels U, Bouffet E. Diffuse brainstem glioma in children: critical review of clinical trials. Lancet Oncol 2006;7:241–8.

9. Louis DN OH, Wiestler OD, Cavanee WK, editors. WHO classification of tumours of the central nervous system. Lyon, France: International Agency for Research on Cancer; 2007.

10. Smoll NR. Relative survival of childhood and adult medulloblastomas and primitive neuroectodermal tumors (PNETs). Cancer 2012;118: 1313–22.

11. Kleihues P, Burger PC, Scheithauer BW. The new WHO classification of brain tumours. Brain Pathol 1993;3:255–68.

12. Rutkowski S, von Hoff K, Emser A, Zwiener I, Pietsch T, Figarella-Branger D, et al. Survival and prognostic factors of early childhood medulloblastoma: an international meta-analysis. J Clin Oncol 2010; 28:4961–8.

13. Kool M, Korshunov A, Remke M, Jones DT, Schlanstein M, Northcott PA, et al. Molecular subgroups of medulloblastoma: an international meta-analysis of transcriptome, genetic aberrations, and clinical data of WNT, SHH, Group 3, and Group 4 medulloblastomas. Acta Neuropathol 2012;123:473–84.

14. Woehrer A, Slavc I, Waldhoer T, Heinzl H, Zielonke N, Czech T, et al. Incidence of atypical teratoid/rhabdoid tumors in children: a population-based study by the Austrian Brain Tumor Registry, 1996–2006. Cancer 2010;116:5725–32.

15. Ostrom QT, Chen Y, Blank Pd, Ondracek A, Farah P, Gittleman H, et al. The descriptive epidemiology of atypical teratoid/rhabdoid tumors in the United States, 2001–2010. Neuro Oncol 2014;16: 1392–9.

16. Lafay-Cousin L, Hawkins C, Carret AS, Johnston D, Zelcer S, Wilson B, et al. Central nervous system atypical teratoid rhabdoid tumours: the Canadian Paediatric Brain Tumour Consortium experience. Eur J Cancer 2012;48:353–9.

17. Hilden JM, Meerbaum S, Burger P, Finlay J, Janss A, Scheithauer BW, et al. Central nervous system atypical teratoid/rhabdoid tumor: results of therapy in children enrolled in a registry. J Clin Oncol 2004;22:2877–84.

18. von Hoff K, Hinkes B, Dannenmann-Stern E, von Bueren AO, Warmuth-Metz M, Soerensen N, et al. Frequency, risk-factors and survival of children with atypical teratoid rhabdoid tumors (AT/RT) of the CNS diagnosed between 1988 and 2004, and registered to the German HIT database. Pediatr Blood Cancer 2011;57:978–85.

19. Athale UH, Duckworth J, Odame I, Barr R. Childhood atypical teratoid rhabdoid tumor of the central nervous system: a meta-analysis of observational studies. J Pediatr Hematol Oncol 2009;31:651–63.

20. Lee JY, Kim IK, Phi JH, Wang KC, Cho BK, Park SH, et al. Atypical teratoid/rhabdoid tumors: the need for more active therapeutic measures in younger patients. J Neuro Oncol 2012;107:413–9.

21. Heck JE, Lombardi CA, Cockburn M, Meyers TJ, Wilhelm M, Ritz B. Epidemiology of rhabdoid tumors of early childhood. Pediatr Blood Cancer 2013;60:77–81.

22. Bishop AJ, McDonald MW, Chang AL, Esiashvili N. Infant brain tumors: incidence, survival, and the role of radiation based on Surveillance, Epidemiology, and End Results (SEER) data. Int J Radiat Oncol Biol Phys 2012;82:341–7.

23. Stefanaki K, Alexiou GA, Stefanaki C, Prodromou N. Tumors of central and peripheral nervous system associated with inherited genetic syndromes. Pediatr Neurosurg 2012;48:271–85.

24. Hottinger AF, Khakoo Y. Neurooncology of familial cancer syndromes. J Child Neurol 2009;24:1526–35.

25. Bourdeaut F, Miquel C, Richer W, Grill J, Zerah M, Grison C, et al. Rubinstein-Taybi syndrome predisposing to non-WNT, non-SHH, group 3 medulloblastoma. Pediatr Blood Cancer 2014;61:383–6.

26. Yu CL, Tucker MA, Abramson DH, Furukawa K, Seddon JM, Stovall M, et al. Cause-specific mortality in long-term survivors of retinoblastoma. J Natl Cancer Inst 2009;101:581–91.

27. Dearlove JV, Fisher PG, Buffler PA. Family history of cancer among children with brain tumors: a critical review. J Pediatr Hematol Oncol 2008;30:8–14.

28. Searles Nielsen S, Mueller BA, Preston-Martin S, Holly EA, Little J, Bracci PM, et al. Family cancer history and risk of brain tumors in children: results of the SEARCH international brain tumor study. Cancer Causes Control 2008;19:641–8.

29. Hemminki K, Kyyronen P, Vaittinen P. Parental age as a risk factor of childhood leukemia and brain cancer in offspring. Epidemiology 1999;10:271–5.

30. Yip BH, Pawitan Y, Czene K. Parental age and risk of childhood cancers: a population-based cohort study from Sweden. Int J Epidemiol 2006;35:1495–503.

31. Johnson KJ, Carozza SE, Chow EJ, Fox EE, Horel S, McLaughlin CC, et al. Parental age and risk of childhood cancer: a pooled analysis. Epidemiology 2009;20:475–83.

32. Weinberg CR, Wilcox AJ, Lie RT. A log-linear approach to case-parent-triad data: assessing effects of disease genes that act either directly or through maternal effects and that may be subject to parental imprinting. Am J Hum Genet 1998;62:969–78.

33. Lupo PJ, Nousome D, Okcu MF, Chintagumpala M, Scheurer ME. Maternal variation in EPHX1, a xenobiotic metabolism gene, is associated with childhood medulloblastoma: an exploratory case-parent triad study. Pediatr Hematol Oncol 2012;29: 679–85.

34. Chen C, Xu T, Chen J, Zhou J, Yan Y, Lu Y, et al. Allergy and risk of glioma: a meta-analysis. Eur J Neurol 2011;18:387–95.

35. Bayley KB, Belnap T, Savitz L, Masica AL, Shah N, Fleming NS. Challenges in using electronic health record data for CER: experience of 4 learning organizations and solutions applied. Med Care 2013;51: S80–6.

36. Harding NJ, Birch JM, Hepworth SJ, McKinney PA. Atopic dysfunction and risk of central nervous system tumours in children. Eur J Cancer 2008;44:92–9.

37. Roncarolo F, Infante-Rivard C. Asthma and risk of brain cancer in children. Cancer Causes Control 2012;23:617–23.

38. Shu X, Prochazka M, Lannering B, Schuz J, Roosli M, Tynes T, et al. Atopic conditions and brain tumor risk in children and adolescents–an international case-control study (CEFALO). Ann Oncol 2014;25: 902–8.

39. Fear NT, Roman E, Ansell P, Bull D. Malignant neoplasms of the brain during childhood: the role of prenatal and neonatal factors (United Kingdom). Cancer Causes Control 2001;12:443–9.

40. Nyari TA, Dickinson HO, Parker L. Childhood cancer in relation to infections in the community during pregnancy and around the time of birth. Int J Cancer 2003;104:772–7.

41. Dickinson HO, Nyari TA, Parker L. Childhood solid tumours in relation to infections in the community in Cumbria during pregnancy and around the time of birth. Br J Cancer 2002;87:746–50.

42. Altieri A, Castro F, Bermejo JL, Hemminki K. Association between number of siblings and nervous system tumors suggests an infectious etiology. Neurology 2006;67:1979–83.

43. Shaw AK, Li P, Infante-Rivard C. Early infection and risk of childhood brain tumors (Canada). Cancer Causes Control 2006;17: 1267–74.

44. Harding NJ, Birch JM, Hepworth SJ, McKinney PA. Infectious exposure in the first year of life and risk of central nervous system tumors in children: analysis of day care, social contact, and overcrowding. Cancer Causes Control 2009;20:129–36.

45. Harding NJ, Birch JM, Hepworth SJ, McKinney PA, Investigators U. Breastfeeding and risk of childhood CNS tumours. Br J Cancer 2007;96:815–7.

46. Andersen TV, Schmidt LS, Poulsen AH, Feychting M, Roosli M, Tynes T, et al. Patterns of exposure to infectious diseases and social contacts in early life and risk of brain tumours in children and adolescents: an International Case-Control Study (CEFALO). Br J Cancer 2013;108:2346–53.

47. Kobayashi N, Furukawa T, Takatsu T. Congenital anomalies in children with malignancy. Paediatr Univ Tokyo 1968;16:31–7.

48. Miller RW. Relation between cancer and congenital defects in man. N Engl J Med 1966;275:87–93.

49. Miller RW. Childhood cancer and congenital defects. A study of U.S. death certificates during the period 1960–1966. Pediatr Res 1969;3: 389–97.

50. Agha MM, Williams JI, Marrett L, To T, Zipursky A, Dodds L. Congenital abnormalities and childhood cancer. Cancer 2005;103: 1939–48.

51. Bjorge T, Cnattingius S, Lie RT, Tretli S, Engeland A. Cancer risk in children with birth defects and in their families: a population based cohort study of 5.2 million children from Norway and Sweden. Cancer Epidemiol Biomarkers Prev 2008;17:500–6.

52. Fisher PG, Reynolds P, Von Behren J, Carmichael SL, Rasmussen SA, Shaw GM. Cancer in children with nonchromosomal birth defects. J Pediatr 2012;160:978–83.

53. Partap S, MacLean J, Von Behren J, Reynolds P, Fisher PG. Birth anomalies and obstetric history as risks for childhood tumors of the central nervous system. Pediatrics 2011;128:e652–7.

54. Bjorge T, Sorensen HT, Grotmol T, Engeland A, Stephansson O, Gissler M, et al. Fetal growth and childhood cancer: a population-based study. Pediatrics 2013;132:e1265–75.

55. Schmidt LS, Schüz J, Lähteenmäki P, Träger C, Stokland T, Gustafson G, et al. Fetal growth, preterm birth, neonatal stress and risk for CNS tumors in children: a Nordic population- and register-based case-control study. Cancer Epidemiol Biomarkers Prev 2010;19:1042–52.

56. Milne E, Laurvick CL, Blair E, de Klerk N, Charles AK, Bower C. Fetal growth and the risk of childhood CNS tumors and lymphomas in Western Australia. Int J Cancer 2008;123:436–43.

57. MacLean J, Partap S, Reynolds P, Von Behren J, Fisher PG. Birth weight and order as risk factors for childhood central nervous system tumors. J Pediatr 2010;157:450–5.

58. Harder T, Plagemann A, Harder A. Birth weight and subsequent risk of childhood primary brain tumors: a meta-analysis. Am J Epidemiol 2008;168:366–73.

59. Kleinerman RA. Cancer risks following diagnostic and therapeutic radiation exposure in children. Pediatr Radiol 2006;36 Suppl 2:121–5.

60. Ohgaki H, Kleihues P. Epidemiology and etiology of gliomas. Acta Neuropathol 2005;109:93–108.

61. Streffer C, Shore R, Konermann G, Meadows A, Uma Devi P, Preston Withers J, et al. Biological effects after prenatal irradiation (embryo and fetus). A report of the International Commission on Radiological Protection. Ann ICRP 2003;33:5–206.

62. Neglia JP, Robison LL, Stovall M, Liu Y, Packer RJ, Hammond S, et al. New primary neoplasms of the central nervous system in survivors of childhood cancer: a report from the Childhood Cancer Survivor Study. J Natl Cancer Inst 2006;98:1528–37.

63. Mellemkjaer L, Hasle H, Gridley G, Johansen C, Kjaer SK, Frederiksen K, et al. Risk of cancer in children with the diagnosis immaturity at birth. Paediatr Perinat Epidemiol 2006;20:231–7.

64. Stalberg K, Haglund B, Axelsson O, Cnattingius S, Pfeifer S, Kieler H. Prenatal X-ray exposure and childhood brain tumours: a population-based case-control study on tumour subtypes. Br J Cancer 2007;97:1583–7.

65. Khan S, Evans AA, Rorke-Adams L, Orjuela MA, Shiminski-Maher T, Bunin GR. Head injury, diagnostic X-rays, and risk of medulloblastoma and primitive neuroectodermal tumor: a Children's Oncology Group study. Cancer Causes Control 2010;21:1017–23.

66. Rajaraman P, Simpson J, Neta G, Berrington de Gonzalez A, Ansell P, Linet MS, et al. Early life exposure to diagnostic radiation and ultrasound scans and risk of childhood cancer: case-control study. BMJ 2011;342:d472.

67. Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet 2012;380:499–505.

68. Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ 2013;346:f2360.

69. Boice JD Jr, Mumma MT, Blot WJ, Heath CW Jr. Childhood cancer mortality in relation to the St Lucie nuclear power station. J Radiol Prot 2005;25:229–40.

70. International Agency for Cancer Research. Agents classified by the IARC Monographs, Volumes 1–109. Lyon: IARC; 2014 [cited 2014 May 7]. Available from: http://monographs.iarc.fr/ENG/Classification/

71. Ha M, Im H, Lee M, Kim HJ, Kim BC, Gimm YM, et al. Radio-frequency radiation exposure from AM radio transmitters and childhood leukemia and brain cancer. Am J Epidemiol 2007;166:270–9.

72. Mezei G, Gadallah M, Kheifets L. Residential magnetic field exposure and childhood brain cancer: a meta-analysis. Epidemiology 2008;19:424–30.

73. Kheifets L, Ahlbom A, Crespi CM, Feychting M, Johansen C, Monroe J, et al. A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors. Am J Epidemiol 2010;172:752–61.

74. Elliott P, Toledano MB, Bennett J, Beale L, de Hoogh K, Best N, et al. Mobile phone base stations and early childhood cancers: case-control study. BMJ 2010;340:c3077.

75. Aydin D, Feychting M, Schuz J, Tynes T, Andersen TV, Schmidt LS, et al. Mobile phone use and brain tumors in children and adolescents: a multicenter case-control study. J Natl Cancer Inst 2011;103:1264–76.

76. McKean-Cowdin R, Pogoda JM, Lijinsky W, Holly EA, Mueller BA, Preston-Martin S. Maternal prenatal exposure to nitrosatable drugs and childhood brain tumours. Int J Epidemiol 2003;32:211–7.

77. Carozza SE, Olshan AF, Faustman EM, Gula MJ, Kolonel LN, Austin DF, et al. Maternal exposure to N-nitrosatable drugs as a risk factor for childhood brain tumours. Int J Epidemiol 1995;24:308–12.

78. Cardy AH, Little J, McKean-Cowdin R, Lijinsky W, Choi NW, Cordier S, et al. Maternal medication use and the risk of brain tumors in the offspring: the SEARCH international case-control study. Int J Cancer 2006;118:1302–8.

79. Schuz J, Weihkopf T, Kaatsch P. Medication use during pregnancy and the risk of childhood cancer in the offspring. Eur J Pediatr 2007;166:433–41.

80. Chuang CH, Doyle P, Wang JD, Chang PJ, Lai JN, Chen PC. Herbal medicines during pregnancy and childhood cancers: an analysis of data from a pregnancy cohort study. Pharmacoepidemiol Drug Saf 2009;18:1119–20.

81. Stalberg K, Haglund B, Stromberg B, Kieler H. Prenatal exposure to medicines and the risk of childhood brain tumor. Cancer Epidemiol 2010;34:400–4.

82. Kaatsch P, Scheidemann-Wesp U, Schuz J. Maternal use of antibiotics and cancer in the offspring: results of a case-control study in Germany. Cancer Causes Control 2010;21:1335–45.

83. Goh YI, Koren G. Prenatal supplementation with multivitamins and the incidence of pediatric cancers: clinical and methodological considerations. Pediatr Blood Cancer 2008;50:487–9; discussion 98.

84. Bunin GR, Kushi LH, Gallagher PR, Rorke-Adams LB, McBride ML, Cnaan A. Maternal diet during pregnancy and its association with medulloblastoma in children: a children's oncology group study (United States). Cancer Causes Control 2005;16:877–91.

85. Bunin GR, Gallagher PR, Rorke-Adams LB, Robison LL, Cnaan A. Maternal supplement, micronutrient, and cured meat intake during pregnancy and risk of medulloblastoma during childhood: a children's oncology group study. Cancer Epidemiol Biomarkers Prev 2006;15:1660–7.

86. Ortega-Garcia JA, Ferris-Tortajada J, Claudio L, Soldin OP, Sanchez-Sauco MF, Fuster-Soler JL, et al. Case control study of periconceptional folic acid intake and nervous system tumors in children. Childs Nerv Syst 2010;26:1727–33.

87. Milne E, Greenop KR, Bower C, Miller M, van Bockxmeer FM, Scott RJ, et al. Maternal use of folic acid and other supplements and risk of childhood brain tumors. Cancer Epidemiol Biomarkers Prev 2012;21:1933–41.

88. Grupp SG, Greenberg ML, Ray JG, Busto U, Lanctot KL, Nulman I, et al. Pediatric cancer rates after universal folic acid flour fortification in Ontario. J Clin Pharmacol 2011;51:60–5.

89. Linabery AM, Johnson KJ, Ross JA. Childhood cancer incidence trends in association with US folic acid fortification (1986–2008). Pediatrics 2012;129:1125–33.

90. Huncharek M. Maternal intake of N-nitroso compounds from cured meat and the risk of pediatric brain tumors: a review. J Environ Pathol Toxicol Oncol 2010;29:245–53.

91. Huncharek M, Kupelnick B. A meta-analysis of maternal cured meat consumption during pregnancy and the risk of childhood brain tumors. Neuroepidemiology 2004;23:78–84.

92. Pogoda JM, Preston-Martin S, Howe G, Lubin F, Mueller BA, Holly EA, et al. An international case-control study of maternal diet during pregnancy and childhood brain tumor risk: a histology-specific analysis by food group. Ann Epidemiol 2009;19:148–60.

93. Searles Nielsen S, Mueller BA, Preston-Martin S, Farin FM, Holly EA, McKean-Cowdin R. Childhood brain tumors and maternal cured meat consumption in pregnancy: differential effect by glutathione S-transferases. Cancer Epidemiol Biomarkers Prev 2011;20:2413–9.

94. Infante-Rivard C, El-Zein M. Parental alcohol consumption and childhood cancers: a review. J Toxicol Environ Health B Crit Rev 2007;10:101–29.

95. Milne E, Greenop KR, Scott RJ, de Klerk NH, Bower C, Ashton LJ, et al. Parental alcohol consumption and risk of childhood acute lymphoblastic leukemia and brain tumors. Cancer Causes Control 2013;24:391–402.

96. Bunin GR, Buckley JD, Boesel CP, Rorke LB, Meadows AT. Risk factors for astrocytic glioma and primitive neuroectodermal tumor of the brain in young children: a report from the Children's Cancer Group. Cancer Epidemiol Biomarkers Prev 1994;3:197–204.

97. Norman MA, Holly EA, Ahn DK, Preston-Martin S, Mueller BA, Bracci PM. Prenatal exposure to tobacco smoke and childhood brain tumors: results from the United States West Coast childhood brain tumor study. Cancer Epidemiol Biomarkers Prev 1996;5: 127–33.

98. Filippini G, Maisonneuve P, McCredie M, Peris-Bonet R, Modan B, Preston-Martin S, et al. Relation of childhood brain tumors to exposure of parents and children to tobacco smoke: the SEARCH international case-control study. Surveillance of environmental aspects related to cancer in humans. Int J Cancer 2002;100: 206–13.

99. Huncharek M, Kupelnick B, Klassen H. Maternal smoking during pregnancy and the risk of childhood brain tumors: a meta-analysis of 6566 subjects from twelve epidemiological studies. J Neuro Oncol 2002;57:51–7.

100. Brooks DR, Mucci LA, Hatch EE, Cnattingius S. Maternal smoking during pregnancy and risk of brain tumors in the offspring. A prospective study of 1.4 million Swedish births. Cancer Causes Control 2004;15:997–1005.

101. Barrington-Trimis JL, Searles Nielsen S, Preston-Martin S, Gauderman WJ, Holly EA, Farin FM, et al. Parental smoking and risk of childhood brain tumors by functional polymorphisms in polycyclic aromatic hydrocarbon metabolism genes. PLoS ONE 2013;8: e79110.

102. Infante-Rivard C, Weichenthal S. Pesticides and childhood cancer: an update of Zahm and Ward's 1998 review. J Toxicol Environ Health B Crit Rev 2007;10:81–99.

103. Pearce MS, Hammal DM, Dorak MT, McNally RJ, Parker L. Paternal occupational exposure to pesticides or herbicides as risk factors for cancer in children and young adults: a case-control study from the North of England. Arch Environ Occup Health 2006;61:138–44.

104. Shim YK, Mlynarek SP, van Wijngaarden E. Parental exposure to pesticides and childhood brain cancer: U.S. Atlantic coast childhood brain cancer study. Environ Health Perspect 2009;117:1002–6.

105. Greenop KR, Peters S, Bailey HD, Fritschi L, Attia J, Scott RJ, et al. Exposure to pesticides and the risk of childhood brain tumors. Cancer Causes Control 2013;24:1269–78.

106. Vinson F, Merhi M, Baldi I, Raynal H, Gamet-Payrastre L. Exposure to pesticides and risk of childhood cancer: a meta-analysis of recent epidemiological studies. Occup Environ Med 2011;68:694–702.

107. Van Maele-Fabry G, Hoet P, Lison D. Parental occupational exposure to pesticides as risk factor for brain tumors in children and young adults: a systematic review and meta-analysis. Environ Int 2013;56: 19–31.

108. World Health Organization. Extremely low frequency fields [Internet]. Lyon: IARC; 2007 [cited 2014 May 7]. Available from: http://www.who.int/peh-emf/publications/Complet_DEC_2007.pdf.

109. Pearce MS, Hammal DM, Dorak MT, McNally RJ, Parker L. Paternal occupational exposure to electro-magnetic fields as a risk factor for cancer in children and young adults: a case-control study from the North of England. Pediatr Blood Cancer 2007;49:280–6.

110. Li P, McLaughlin J, Infante-Rivard C. Maternal occupational exposure to extremely low frequency magnetic fields and the risk of brain cancer in the offspring. Cancer Causes Control 2009;20:945–55.

111. Hug K, Grize L, Seidler A, Kaatsch P, Schuz J. Parental occupational exposure to extremely low frequency magnetic fields and childhood cancer: a German case-control study. Am J Epidemiol 2010;171: 27–35.

112. Ali R, Yu CL, Wu MT, Ho CK, Pan BJ, Smith T, et al. A case-control study of parental occupation, leukemia, and brain tumors in an industrial city in Taiwan. J Occup Environ Med 2004;46: 985–92.

113. Mazumdar M, Liu CY, Wang SF, Pan PC, Wu MT, Christiani DC. No association between parental or subject occupation and brain tumor risk. Cancer Epidemiol Biomarkers Prev 2008;17: 1835–7.

114. Peters S, Glass DC, Reid A, de Klerk N, Armstrong BK, Kellie S, et al. Parental occupational exposure to engine exhausts and childhood brain tumors. Int J Cancer 2013;132:2975–9.

115. Greenop KR, Peters S, Fritschi L, Glass DC, Ashton LJ, Bailey HD, et al. Exposure to household painting and floor treatments, and parental occupational paint exposure and risk of childhood brain tumors: results from an Australian case-control study. Cancer Causes Control 2014;25:283–91.

116. Cordier S, Monfort C, Filippini G, Preston-Martin S, Lubin F, Mueller BA, et al. Parental exposure to polycyclic aromatic hydrocarbons and the risk of childhood brain tumors: the SEARCH International Childhood Brain Tumor Study. Am J Epidemiol 2004; 159:1109–16.

117. Baldwin RT, Preston-Martin S. Epidemiology of brain tumors in childhood–a review. Toxicol Appl Pharmacol 2004;199:118–31.

118. Son M, Kim J, Oh J, Kawachi I. Inequalities in childhood cancer mortality according to parental socioeconomic position: a birth cohort study in South Korea. Soc Sci Med 2011;72:108–15.

119. Keegan TJ, Bunch KJ, Vincent TJ, King JC, O'Neill KA, Kendall GM, et al. Case-control study of paternal occupation and social class with risk of childhood central nervous system tumours in Great Britain, 1962–2006. Br J Cancer 2013;108:1907–14.

120. Gurney JG, Smith MA, Olshan AF, Hecht SS, Kasum CM. Clues to the etiology of childhood brain cancer: N-nitroso compounds, polyomaviruses, and other factors of interest. Cancer Invest 2001; 19:630–40.

121. Zahm SH, Ward MH. Pesticides and childhood cancer. Environ Health Perspect 1998;106 Suppl 3:893–908.

122. Rosso AL, Hovinga ME, Rorke-Adams LB, Spector LG, Bunin GRChildren's Oncology G. A case-control study of childhood brain tumors and fathers' hobbies: a Children's Oncology Group study. Cancer Causes Control 2008;19:1201–7.

123. Searles Nielsen S, Mueller BA, De Roos AJ, Viernes HM, Farin FM, Checkoway H. Risk of brain tumors in children and susceptibility to organophosphorus insecticides: the potential role of paraoxonase (PON1). Environ Health Perspect 2005;113:909–13.

124. Searles Nielsen S, McKean-Cowdin R, Farin FM, Holly EA, Preston-Martin S, Mueller BA. Childhood brain tumors, residential insecticide exposure, and pesticide metabolism genes. Environ Health Perspect 2010;118:144–9.

125. Ward E, DeSantis C, Robbins A, Kohler B, Jemal A. Childhood and adolescent cancer statistics, 2014. CA Cancer J Clin 2014;64: 83–103.

126. Heiden TL, Bailey HD, Armstrong BK, Milne E. Participation in paediatric cancer studies: timing and approach to recruitment. BMC Res Notes 2013;6:191.

127. The Children's Oncology Group. Project: every child [Internet]. Philadelphia: The Children's Oncology Group; [cited 2014 May 14]. Available from: http://projecteverychild.org/

128. Peris-Bonet R, Martinez-Garcia C, Lacour B, Petrovich S, Giner-Ripoll B, Navajas A, et al. Childhood central nervous system

tumours–incidence and survival in Europe (1978–1997): report from Automated Childhood Cancer Information System project. Eur J Cancer 2006;42:2064–80.

129. Makino K, Nakamura H, Yano S, Kuratsu JKumamoto Brain Tumor Group. Population-based epidemiological study of primary intracranial tumors in childhood. Childs Nerv Syst 2010;26:1029–34.

130. Katchy KC, Alexander S, Al-Nashmi NM, Al-Ramadan A. Epidemiology of primary brain tumors in childhood and adolescence in Kuwait. SpringerPlus 2013;2:58.

131. Schmidt LS, Schmiegelow K, Lahteenmaki P, Trager C, Stokland T, Grell K, et al. Incidence of childhood central nervous system tumors in the Nordic countries. Pediatr Blood Cancer 2011;56:65–9.

132. Raaschou-Nielsen O, Sorensen M, Carstensen H, Jensen T, Bernhardtsen T, Gjerris F, et al. Increasing incidence of childhood tumours of the central nervous system in Denmark, 1980–1996. Br J Cancer 2006;95:416–22.

133. Arora RS, Alston RD, Eden TO, Estlin EJ, Moran A, Birch JM. Age-incidence patterns of primary CNS tumors in children, adolescents, and adults in England. Neuro Oncol 2009;11:403–13.

134. Steliarova-Foucher E, Stiller C, Lacour B, Kaatsch P. International classification of childhood cancer, third edition. Cancer 2005;103: 1457–67.

135. Lannering B, Sandstrom PE, Holm S, Lundgren J, Pfeifer S, Samuelsson U, et al. Classification, incidence and survival analyses of children with CNS tumours diagnosed in Sweden 1984–2005. Acta Paediatr 2009;98:1620–7.

136. Connelly JM, Malkin MG. Environmental risk factors for brain tumors. Curr Neurol Neurosci Rep 2007;7:208–14.

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