Imaging of
Pediatric Brain Tumors

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Learning objectives:

- Basics of anatomical imaging
- Key findings of advanced imaging techniques
- Learn imaging characteristics of selected pediatric brain tumours
- Formulate basic differential diagnoses based on these imaging features
- “pearls of wisdom” for image interpretation that can lead to specific diagnosis
Disclosures, acknowledgements

- No disclosures
- Many acknowledgements!
- This talk: X-C Wei, MD, FRCPC, Diagnostic Imaging, Alberta Children’s Hospital
- Faculty/fellows UCalgary Neuroradiology, (particularly James Scott)
- UCSF Neuroradiology/Neuropathology
Some general stuff about tumour imaging: “anatomical imaging”

- T1, T2, FLAIR
- Post-contrast T1
- Single plane or volumetric with MPR’s
Tumour margins

• Well defined, “smooth” = lower grade
• Irregular/infiltrative = higher grade
Low grade glioma
High grade glioma
Contrast enhancement

• Generally correlated with increased vascularity and higher grade
• BUT not necessarily – many low grade tumours enhance
• Consider enhancement in the context of the other features of the tumour to determine whether it is indicating something more benign vs malignant
A bunch o’ GBM’s
Enhancement looks worrisome...

Juvenile Pilocytic Astrocytoma
WHO Grade I
“Advanced Imaging”

- Perfusion
- Diffusion
- Spectroscopy
The tumor region (A, B, and C) is easily detectable in the CBV image as an area of increased blood volume, reflecting angiogenesis. Higher-grade tumors tend to have higher values, as in this glioblastoma.

**DSC-derived CBV most commonly used parameter**
Tumour cellularity

• Densely cellular tumours:
  – Hyperdense on CT
  – Darker on T2W
  – Bright on DWI/decreased ADC
Low grade glioma, -ve DWI
Anaplastic astrocytoma, restricted diffusion
Spectroscopy

- Choline – membrane turnover
- Creatine – energy synthesis
- NAA – neuronal marker
- Lactate – anaerobic metabolism/necrosis
- Lipid – cellular/myelin breakdown products, nonviable/necrotic tissue

**HALLMARK OF TUMOURS:** elevated Choline/decreased NAA
Representative proton-1 MR spectroscopy (1H-MRS) spectrum acquired with parameters TR/TE = 2000/31 ms on a 3T MR imaging scanner.
1H-MR spectroscopy of medulloblastoma. 1H spectra of a solid-appearing medulloblastoma (A) and of a medulloblastoma with necrotic/cystic areas (B) and corresponding T2-weighted transverse fast spin-echo MR image [repetition time (TR)/echo time (TE), 3500/85...


\textbf{\textsuperscript{1}H-MRS in Evaluation of Brain Tumors in Children}

- Allows us to monitor important brain metabolites
- Numerous studies and papers; results are mixed

- Can be used to
  - identify tumor tissue
  - grade tumors
  - differentiate tumor types
  - distinguish active tumors from radiation necrosis or scar tissue
  - guide stereotactic biopsy site
  - determine early response to treatment

- Often nonspecific
- Significant overlap between tumor types in individual cases
- Inflammatory lesions can have spectra identical to those of malignant tumor

MR Spectroscopy in Tumor Grading

- In adults, higher grade gliomas were correlated with higher Cho/Cr ratios than low-grade gliomas.
- In children, pilocytic astrocytomas (WHO grade I) have high Cho/Cr ratios mimicking high grade tumors.
The 2016 World Health Organization Classification of Tumors of the Central Nervous System: a summary

David N. Louis¹ · Arie Perry² · Guido Reifenberger³,⁴ · Andreas von Deimling⁴,⁵ · Dominique Figarella-Branger⁶ · Webster K. Cavenee⁷ · Hiroko Ohgaki⁸ · Otmar D. Wiestler⁹ · Paul Kleihues¹⁰ · David W. Ellison¹¹
Pediatric Brain Tumors

- 2nd most common type of cancer in children (17% of all childhood cancer)
- 2nd most common cause of cancer deaths (25%) in children
- diverse and heterogeneous in pathology, biologic behavior and imaging appearance
Pediatric brain tumors occur in a different ratio than adult brain tumors: for example primary to secondary.

Even the types of primary brain tumors are different in children.

Brain tumours in children

• AGE and LOCATION are key
• Neonates and up to 2 years = supratentorial more common
• >2 years infratentorial more common
### Posterior Fossa Tumors in Children

<table>
<thead>
<tr>
<th>Common</th>
<th>Uncommon</th>
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<tbody>
<tr>
<td><strong>Cerebellar/intraventricular</strong></td>
<td><strong>Intraparenchymal</strong></td>
</tr>
<tr>
<td>Medulloblastoma</td>
<td>Teratoma</td>
</tr>
<tr>
<td>Astrocytoma</td>
<td>Hemangioblastoma</td>
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<tr>
<td>Ependymoma</td>
<td><strong>Extraparenchymal</strong></td>
</tr>
<tr>
<td>Atypical teratoid/rhabdoid tumor (AT/RT)</td>
<td>Dermoid/Epidermoid</td>
</tr>
<tr>
<td><strong>Brainstem glioma</strong></td>
<td>Enterogeneous (enteric) cyst</td>
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<tr>
<td></td>
<td>Teratoma</td>
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<tr>
<td></td>
<td>Schwannoma</td>
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<td></td>
<td>Meningioma</td>
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<td>Skull base tumors</td>
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</table>
Medulloblastoma

- 2nd most common brain tumor (after astrocytoma)
- Most common malignant brain tumor
- Account for 30-40% of pediatric posterior fossa tumors

- Highly malignant tumor (WHO grade IV)

- Composed of primitive, undifferentiated, small round cells

- Histologically similar to
  - supra-tentorial primitive neuroectodermal tumor (PNET)
  - pineoblastoma
  - peripheral neuroblastoma
Medulloblastoma

Most reliable imaging feature for DDx of cerebellar/4th ventricle tumor: **hyperdense** on pre-contrast CT (~90%) 

Presumably due to high nuclear-to-cytoplasmic ratio of the small round cells

Medulloblastoma

Age and tumor location are also very helpful for diagnosis

- Mean age: 7.3 years
- 70-90% originate from inferior medullary velum, projecting into 4th ventricle
- Usually located in midline vermis in very young, whereas in adolescents and adults most often hemispheric
Growth “vector”: medulloblastoma
Medulloblastoma

- T1 hypo-/isointense
- T2 isointense or slightly hyperintense to GM
- Variable enhancement

- Surrounding edema, hydrocephalus common

- Cyst and Ca++ uncommon. If occur, necrotic microcysts, fine granular Ca++
Ependymoma

- 4th most common posterior fossa tumor in children, after medulloblastoma, cerebellar astrocytoma, and brainstem glioma

- In children, 65% infratentorial, 25% supratentorial, 10% intraspinal, whereas supratentorial dominant in adults

- Infratentorial ependymomas have two age peaks: 5 years and 35 years. M≈F
Growth “vector”: Ependymoma
Ependymoma

- CT: iso-/hyperdense 4th ventricle mass with punctate Ca\(^{++}\) (50%), small cysts (15%), and moderate enhancement

- MR: T1W iso-/hypointense, T2W iso-/hyperintense, heterogeneous enhancement
Ependymoma: Most Characteristic Findings

Tumor extension through –

- foramen of Magendie and foramen magnum into dorsal cervical CSF space, ~ 60%
- foramen of Luschka into C-P angle cistern with insinuation around blood vessels and cranial nerves, ~ 15%
Cerebellar Astrocytoma

- Most common are juvenile pilocytic astrocytoma (JPA)
  - the most benign astroglial tumor, WHO grade I
  - peak incidence from birth to 9 years
  - excellent prognosis

- Much less common are anaplastic astrocytomas (WHO grade III): more common in older children
Cerebellar Astrocytoma: Imaging Appearance

- Large vermian or hemispheric tumors, predominantly cystic
- Solid component: usually hypodense on noncontrast CT, T1 hypointense and T2 hyperintense, intense enhancement
Growth “vector”: 
Posterior fossa tumors: CSF dissemination

Medulloblastoma:

- Common: 33% at diagnosis, up to 100% in general
- Spinal MRI w/ Gd the current imaging study of choice
- Sensitivity: 83% MR vs 60-78% CSF cytological analysis
- MR Should be used in combination with CSF cytology
Medulloblastoma: Disseminating along CSF pathways

- Nodular enhancement of cord/brain surface or nerve roots
- Clumped nerve roots
- Diffuse enhancement of thecal sac
Posterior fossa tumors: CSF dissemination

Ependymoma:
- infratentorial ependymoma: not uncommon (1/3), but rarely at presentation. Always intraspinal
- Supratentorial intraventricular ependymoma: uncommon. Usually supratentorial if occurs

Astrocytoma:
- CSF dissemination extremely rare
When to image the spine to assess for intraspinal drop metastasis?

- Ideally preoperatively
- In first few weeks after craniotomy, common artifacts from dependent subarachnoid blood product, contrast material leaked into subarachnoid/subdural spaces; difficult to differentiate from CSF spread of tumor

- Perform pre-op spinal MRI only when medulloblastoma, AT/RT, ependymoma are suspected
  - One of the major reasons to differentiate between post-fossa tumors on pre-op MRI
Brainstem Glioma
Brainstem Glioma

- Constitute about 20-30% of infratentorial pediatric brain tumors
- M = F, peak incidence 3-10 years

- Location predicts tumor type and survival
  (never just say brainstem glioma for a specific case)
  - Medullary, pontine, mesencephalic

- Focal vs diffuse also important
## Brainstem Glioma in Children

<table>
<thead>
<tr>
<th></th>
<th>Diffuse intrinsic gliomas</th>
<th>Dorsal exophytic gliomas/cervicomedullary gliomas</th>
<th>Focal tectal gliomas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>60-80%</td>
<td>20-35%</td>
<td>&lt;5%</td>
</tr>
<tr>
<td><strong>Age of onset</strong></td>
<td>5-10 years</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Duration of symptoms</strong></td>
<td>&lt;2 months</td>
<td>&gt;2 months</td>
<td>&gt;2 months</td>
</tr>
<tr>
<td><strong>Clinical presentations</strong></td>
<td>Ataxia, long tract signs, cranial nerve deficits</td>
<td>H/A, vomiting, swallowing problems, weakness of limbs</td>
<td>Increased ICP, H/A and vomiting</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Pons (DIPG)</td>
<td>Floor of 4th ventricle or cervicomedullary, rarely in midbrain or pons</td>
<td>Tectal plate</td>
</tr>
<tr>
<td><strong>MRI features</strong></td>
<td>Diffuse, prepontine extension, engulf basilar artery, usually no enhancement (enhancement has no prognostic significance)</td>
<td>Focal, posterior exophytic extension, avid enhancement</td>
<td>Focal, well-defined, hydrocephalus, rarely enhance</td>
</tr>
<tr>
<td><strong>Histology</strong></td>
<td>high-grade glioma</td>
<td>Pilocytic astrocytoma</td>
<td>Low-grade glioma</td>
</tr>
<tr>
<td><strong>Treatment</strong></td>
<td>Radiotherapy</td>
<td>Surgical resection</td>
<td>CSF shunt and F/U</td>
</tr>
<tr>
<td><strong>Median survival</strong></td>
<td>1 year</td>
<td>&gt;5 years</td>
<td>&gt;7 years</td>
</tr>
</tbody>
</table>

Growth “vector”:
Diffuse intrinsic (diffusely infiltrative) pontine glioma (DIPG)
Dorsal exophytic medullary glioma (pilocytic)

A 13-year-old female with H/A, vomiting and swallowing problem
Tectal glioma in a 7-yr-old girl c/o bilateral weakness with ataxia
Initial MRI

MRI a year after, Slow growing
Supratentorial Pediatric Brain Tumors in Children

- Cerebral hemispheres 47%
- Sellar/Suprasellar 40%
- Pineal 10%
- Intraventricular 3%
# Cerebral Hemispheric Tumors in Children

## Tumors with Relatively Less-Specific Imaging Appearance
- Astrocytoma
- Ependymoma

## Tumors with Relatively Specific Imaging/Clinical Features
- Subependymal giant cell astrocytoma
- Desmoplastic infantile ganglioglioma (DIG)
- Mixed neuronal-glial tumors (ganglioglioma)
- Dysembryoplastic neuroepithelial tumors (DNET)

## Rare
- Medulloepithelioma
- Plasma cell granuloma
- Meningioangiomatosis
Cerebral Hemispheric Tumors in Children

Common But Having Non-Specific Imaging Appearance
- Astrocytoma
- Ependymoma
- PNET
- Atypical teratoid/rhabdoid tumor

Tumors With Relatively Specific Imaging/Clinical Features
- Subependymal giant cell astrocytoma
- Desmoplastic infantile ganglioglioma (DIG)
- Mixed neuronal-glial tumors
- Dysembryoplastic neuroepithelial tumors (DNET)
- Teratoma

Rare
- Medulloepithelioma
- Meningioangiomatosis
- Plasma cell granuloma
Subependymal Giant Cell Astrocytoma

- WHO grade I, histologically similar to subependymal hamartoma in tuberous sclerosis
- Presents in teens or 20s
Subependymal Giant Cell Astrocytoma: Imaging

- Other features of TSC
- Unique location: caudothalamic groove adjacent to the foramen of Monro
- Well-defined
- Ca++ common, uniform enhancement
- Secondary hydrocephalus
- Slow growth
- Rapid growth or invasion raises suspicion of anaplasia

Imaging appearances are characteristic, almost pathognomonic
Desmoplastic Infantile Ganglioglioma (DIG)

- < 2 years at diagnosis, mostly <1.5 years
- Rapid head growth, increased ICP, hemiparesis, partial complex seizure
- Exclusively supratentorial, hemispheric, with predilection for frontal and parietal lobes
• Massive, hemispheric

• Predominantly cystic, commonly with septation

• Solid component:
  - superficial, commonly attached to dura
  - distinctively hypointense on T2
  - markedly enhancing, nodule or plaque

• 3-month-old boy has large left fronto-parietal lesion with significant mass effect on outside CT.
Recognition of DIG Is Important

- Share some of the neuroradiological and histological findings of malignant astrocytoma and PNET, but have a completely different prognosis
- Histologic findings may be confusing
- Malignant appearance, but benign in prognosis
- Complete resection considered curative
### Epileptogenic Tumors

- Peripherally located, involving the cortical gray matter
- Associated with medically refractory focal epilepsy
- Amenable to surgical resection with favorable prognosis
- Characteristic imaging features

<table>
<thead>
<tr>
<th>Larger Mass</th>
<th>Smaller Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desmoplastic infantile ganglioglioma (DIG)</td>
<td>Dysembryoplastic neuroepithelial tumors (DNET)</td>
</tr>
<tr>
<td>Pleomorphic xanthoastrocytoma (PXA)</td>
<td>Ganglioglioma/gangliocytoma</td>
</tr>
</tbody>
</table>
Dysembryoplastic Neuroepithelial Tumors (DNET)

- **Imaging appearance**
  - *Wedge shaped: cortex to ventricle*
  - *Very bright T2, “microcystic”*
  - *Rim sign on FLAIR*
  - *Enhancement in 20% (if enhancing, may require more intensive follow-up)*
  - *Ca++ rare*

- **Location**
  - *Cortical, scallops inner table*
  - *62% temporal lobe, 31% frontal lobe*
Dysembryoplastic Neuroepithelial Tumors (DNET)

- **Clinical**
  - *No or stable neurological deficit*
  - *Virtually always associated with refractory focal epilepsy*

- **Pathology**
  - *On a background of cortical dysplasia*
  - *Remarkably stable biologic behavior*
6-year-old girl presented with seizure.
A 9-year-old girl presented with fainting spells and medically refractory seizure.
Ganglioglioma

- Clinical features similar to DNET

- Imaging features
  - *Small, well-defined cortical mass, cystic or solid,*
  - *35% Ca++, variable T1W, T2W signal*
  - *variable enhancement, erosion of adjacent calvarium*

- Imaging differentiation from oligodendroglioma or atypical DNET can be difficult
Seller/Suprasellar Tumors in Childhood
## Midline: Seller and Suprasellar Tumors in Childhood

<table>
<thead>
<tr>
<th><strong>Common</strong></th>
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<tbody>
<tr>
<td>Craniopharyngioma</td>
<td>50%</td>
</tr>
<tr>
<td>Astrocytoma</td>
<td>10-15%</td>
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<table>
<thead>
<tr>
<th><strong>Less common</strong></th>
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<tbody>
<tr>
<td>Pituitary adenoma</td>
<td></td>
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<tr>
<td>Rathke's cleft cyst</td>
<td></td>
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<tr>
<td>Germ cell tumor</td>
<td></td>
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<tr>
<td>Hypothalamic hamartoma</td>
<td></td>
</tr>
<tr>
<td>Langerhans' cell histocytosis</td>
<td></td>
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<tr>
<td>Arachnoid cyst</td>
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<table>
<thead>
<tr>
<th><strong>Rare</strong></th>
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<tbody>
<tr>
<td>Lymphocytic hypophysitis</td>
<td></td>
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<tr>
<td>Granuloma (Sarcoidosis or TB)</td>
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</tbody>
</table>
Craniopharyngioma

- Postulated to arise from remnants of the craniopharyngeal duct, but controversial
- Arise anywhere along the pituitary stalk from the floor of the third ventricle to the pituitary gland
- Rarely, may arise below the sella in the sphenoid sinus
- Incidence peaks at 10-14 years, with a second small peak in 40-60 years
- Typical clinical presentation:
  - Headache
  - visual field defects
  - growth failure
  - diabetes insipidus
Craniopharyngioma

- Pathological classification
  - **Adamantinomatous**: in children and adolescents, cystic with Ca++
  - **Papillary**: in adults, predominantly solid, or small cyst

- Surgical classification – relation with chiasm is crucial, always identify!
Craniopharyngioma: MRI/CT Characteristics

- Suprasellar location, may extend into anterior/middle/posterior cranial fossa

- Cystic component >90%
- Ca++ >90%
- Enhancement >90%
Chiasmatic/Hypothalamic Astrocytomomas and Optic Nerve Tumors

- Primary site of origin (chiasmatic or hypothalamic) cannot be determined in many cases
- NF1 in 20-50%
- Usually present at 2-4 years of age
- Diminished visual acuity, optic atrophy
Chiasmatic/Hypothalamic Astrocytomas and Optic Nerve Tumors

- CT – enlargement of optic canal signal of chiasmatic or optic nerve origin, Ca++ unusual

- MRI – $\downarrow T1, \uparrow T2$, variable enhancement
Chiasmatic/hypothalamic astrocytoma (Pilocytic) in a 10-yr-old girl presented with H/A
Pineal Region Tumors in Children
## Pineal Region Tumors in Children

<table>
<thead>
<tr>
<th>Tumor Type</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>Germ cell tumors</td>
<td>50-70%</td>
</tr>
<tr>
<td>Pineal parenchymal tumors</td>
<td>15-30%</td>
</tr>
<tr>
<td>Pineal region gliomas</td>
<td>12%</td>
</tr>
<tr>
<td>Dermoid/Epidermoid cysts</td>
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</tr>
<tr>
<td>Pineal cysts</td>
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</tbody>
</table>
Intracranial Germ Cell Tumors in Children

• Theory of origin: controversial

• Location
  - Pineal 55-60%
  - Suprasellar/hypothalamic 30%
  - Basal ganglial/thalamic 4-14%
  - Multicentric 15%
  - Other: CP angle, cerebral hemisphere, corpus callosum
Germinoma in a 14-year-old boy presented with headaches and visual blurring.

- Germinoma “engulfs” pineal Ca++, pineal parenchymal tumours “explode”
Summary

- Imaging provides essential information for identification, location, characterization, and follow up of pediatric brain tumors.

- Many tumors have highly specific imaging features that allow short list of differential diagnosis.
Test your skills!
A 14-year-old boy post concussion, ataxia and headache.
Answer: Medulloblastoma

a. Medulloblastoma
b. Lymphoma
c. Dysplastic gangliocytoma
d. Solid JPA
Thank you!