CNS Anatomy & Contouring

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Disclosure

No commercial ties or funding have influenced either the content or the delivery of this presentation.
Topics to be Covered

- Anatomy
- Immobilization for CNS radiotherapy
- How MR imaging pulse sequences can contribute to CNS radiotherapy
- Structures relevant to XRT planning & contouring
Anatomy

- The CNS consists of the brain and spinal cord.
- The bony skull and spinal canal (formed by the vertebral bodies) confine the CNS within a series of membranes (meninges) that also contain the cerebrospinal fluid (CSF) surrounding the brain and spinal cord.
- Nerves and blood vessels enter and exit the CNS through bony foraminae.
Anatomy

- Different parts of the brain have different functions (unlike many other organs)
- Gray matter is the location of cell bodies
- White matter is comprised of cell axons (the long cellular processes that conduct electrical impulses throughout the CNS)
- Anatomic derangements disturb function
Several classification schemes may apply:

- Primary vs. metastatic
- Intra- vs. extra-axial
- Curable vs. incurable (curative vs. palliative)
- Operable vs. inoperable
- Benign vs. malignant
- Infiltrative vs. non-infiltrative
- Eloquent vs. non-eloquent location

These factors are important in deciding overall management recommendations and in how radiotherapy may be beneficially used.
Extra-axial tumors arise from superficial CNS components (meningiomas, schwannomas, hemangiopericytomas, paragangliomas, choroid plexus tumors, etc.)

Intra-axial tumors arise from cells within the brain or spinal cord (gliomas, astrocytomas, oligodendrogliomas, ependymomas, mixed gliomas, medulloblastomas, gangliogliomas, pituitary adenomas, pineal tumors, primary CNS lymphoma, etc.)
Metastatic Tumors

- Primarily hematogenous spread
- Tumor cells lodge at gray-white junction where the final capillary beds develop from small arterioles
- Oligometastatic vs. non-oligometastatic
- May also occur by direct extension along nerve roots or through the skull
- Surgical resection is performed to alleviate mass effect or make a tissue diagnosis to guide systemic therapy choices
Radiation Approaches for CNS Tumors

- External beam radiotherapy
  - Whole brain radiotherapy
  - Partial brain radiotherapy
  - Craniospinal radiotherapy
  - Stereotactic Radiosurgery

- Brachytherapy
  - Temporary
  - Permanent
Immobilization requirements differ for various CNS radiotherapy indications

- Single fraction SRS
  - Frame
  - Immobilization mask
  - Dental appliance, etc.

- Multiple fraction SRS
  - Immobilization mask
  - Dental appliance

- Conventionally fractionated partial brain radiotherapy (3DCRT vs. IMRT)

- Whole brain radiation therapy
Frameless Immobilization

- Two thermoplastic layers
- Custom thermoplastic head support
- Spacers needed to adjust ‘tightness’ of mask
- Stereotactic accuracy possible

- One thermoplastic layer
- Standardized head holder
- Generally adequate for immobilization for WBRT and partial brain XRT
Frameless Immobilization

- Setup on base
  - Limits degrees of freedom for beam entry
  - Adequate for coplanar and some non-coplanar treatments

- Setup on table
  - Increased degrees of freedom for beam entry
  - Facilitates non-coplanar treatment with use of extended table-top
Guckenberger et al. *Dosimetric consequences of translational and rotational errors in frame-less image-guided radiosurgery.* [http://www.ro-journal.com/content/7/1/63](http://www.ro-journal.com/content/7/1/63)

CBCT & 6 DOF table used pre & post SRS to check setup accuracy. Pre-IG errors were 3.9 mm ± 1.7 mm (3D vector) & maximum rotational error was 1.7° ± 0.8° on average. The post-SRS 3D error was 0.9 mm ± 0.6 mm. A 1.0 mm margin covered all intra-fractional movement.
Fractionated Stereotactic IMRT
Whole Brain Radiation Therapy (WBRT)

- Treatment covers the entire cranial contents, generally given in 5-15 fractions over 1-3 weeks
- Can be delivered with rectangular portals or with shaped beams
- Generally part of palliative management
- No differential sparing of normal brain cells or other normal tissues relative to tumor cells
- Hot spots of up to 15% are common
- Normal brain function may be adversely affected by hot spots
Innovations may appear to be superior, but assessments proving value are still pending.
Improved Radiation Distribution

Improved dose distribution with IMRT
## Cranial Irradiation—WBRT vs. IMRT

<table>
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<tr>
<th>Pt #</th>
<th>Hot Spot (Gy)</th>
<th>% Contoured brain volume &gt; 105% prescribed dose</th>
<th>% Contoured brain volume &gt; 110% prescribed dose</th>
<th>% Contoured brain volume &gt; 98% prescribed dose</th>
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<tr>
<td></td>
<td>EBRT</td>
<td>IMRT</td>
<td>EBRT</td>
<td>IMRT</td>
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<tr>
<td>1</td>
<td>33.67</td>
<td>31.38</td>
<td>33.30%</td>
<td>0.00%</td>
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<td>33.95</td>
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<td>31.62</td>
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<tr>
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<td>31.71</td>
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<td>33.46</td>
<td>31.35</td>
<td>37.32%</td>
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<td>34.23</td>
<td>31.50</td>
<td>24.63%</td>
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<tr>
<td>Mean</td>
<td>33.78</td>
<td>31.63</td>
<td>29.26%</td>
<td>0.03%</td>
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</table>
Cranial Irradiation—WBRT vs. IMRT

Dose Volume Histogram - Conventional 2-Field Helmet Plan vs. 2-Field IMRT

- IMRT
- Conventional
Partial Brain Radiotherapy
Partial Brain IMRT DRR /Portal Film
Partial Brain IMRT DRR /Portal Film
AUTOMATIC THREE DIMENSIONAL CO-REGISTRATION OF DIAGNOSTIC MRI AND TREATMENT PLANNING CT FOR BRAIN TUMOR RADIOTHERAPY TREATMENT PLANNING

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Proceedings of the 41st Annual ASTRO Meeting
San Antonio, Texas, 10/31-11/4/1999

COMPARISON OF AN IMAGE REGISTRATION TECHNIQUE BASED ON NORMALIZED MUTUAL INFORMATION WITH A STANDARD METHOD UTILIZING IMPLANTED MARKERS IN THE STAGED RADIOSURGICAL TREATMENT OF LARGE ARTERIOVENOUS MALFORMATIONS

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● T2 and FLAIR pulse sequences depict differences in the spin-spin (or $T_2$) relaxation time of various tissues within the body

● In T2 and FLAIR pulse sequences, water is bright, and clearly show tumor-associated edema for target contouring (usually only for infiltrative tumors like gliomas)
- T1 weighted scans show differences in the spin-lattice (or $T_1$) relaxation time of various tissues within the body.
- T1 scans are often obtained before and after i.v. ‘contrast’ agents—most commonly Gadolinium compounds that shorten the T1 relaxation times.
Diffusion MRI measures the diffusion of water molecules in biological tissues.

The fractional anisotropy in each direction in each voxel can be calculated to make brain maps of fiber directions to examine the connectivity of different regions in the brain.
Non-Coplanar or Coplanar?

- Coplanar versus noncoplanar intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) treatment planning for fronto-temporal high-grade glioma*

Cranial Nerves

Provide sensory input, and control muscles, glands, viscera, immune modulation.
Potential organs at risk in CNS radiotherapy include:

- Scalp
- Lenses
- Retinae
- Lacrimal Glands
- Optic Nerves, Chiasm, and Tracts
- Pituitary
- Cochlae
- Hippocampi
- Brainstem
- Cervical Spinal Cord

There are different dose-limiting toxicities for different endpoints in different organs.
Scalp Toxicity

Radiation folliculitis and comedones associated with $^{60}$Co treatment of a frontal glioblastoma using a right and left parallel opposed pair of beams flashing across the anterior scalp to deliver a dose of 60 Gray in 30 fractions.
Scalp Toxicity

- Anaplastic Astrocytoma
- Resected at Mayo Clinic
- 60 Gy partial brain XRT
- Delivered in Florida

http://especiallyheather.com/2008/06/20/so-good-to-be-home/
Pay Attention to the Optics

Lacrima gland is at upper outer corner of eye

- Tolerance dose for a lacrimal gland is ~35 Gy
- Exceeding tolerance causes a dry, painful eye
Pay Attention to the Optics
Pay Attention to the Optics

Optic Nerves

Carotid Arteries
Optic Chiasm

- Craniopharyngioma displacing & compressing optic chiasm
- Fractionated stereotactic radiotherapy to 54 Gy (30 fx), which will not exceed chiasm tolerance
Optic Chiasm

- 10 field IMRT plan, 6 MV photons, with daily stereotactic setup with kV image matching
- Hot spots (56.9 Gy $d_{\text{max}}$) are remote from optic apparatus
Optic Chiasm

- 6 weeks follow-up MRI of craniopharyngioma
- Visual fields have returned to normal
Cochlea—Where the Heck is it?

- The cochlea is located anterior to the internal auditory canal
- Auditory perception is tonotopic
- Different frequencies are heard in different locations
Hippocampi

- Important because of potential adverse impact on short-term memory formation from radiotherapy
- Subependymal stem cells in the subgranular zone are felt to be important in generating short-term memory
- RTOG 0933 tests WBRT with hippocampal avoidance

http://www.rtog.org/CoreLab/ContouringAtlases/HippocampalSparing.aspx
Atypical Meningioma

GTV was generated from preoperative MRI. PTV1 and PTV2 generated by adding 2 cm margin and 1.5 cm margins and editing to cover interhemispheric meninges without treating contralateral cerebral cortex.
Glioblastoma Multiforme

$PTV_1$ (46 Gy) generated from contoured FLAIR and brain volumes, Boolean editing, and respecting anatomic barriers to tumor spread.
Glioblastoma Multiforme

$\text{PTV}_2$ (60 Gy) generated from postoperative volumetric contrast-enhanced MRI, Boolean processes (including $\text{PTV}_1$)
Inaccurate GTV contouring and less-than-logical CTV and PTV generation will increase volumes getting high-dose radiation and may make treatment planning more difficult.

Gliomas will not cross a dural surface (e.g. into the cerebellum from the cerebrum) or a CSF containing space—they spread along white matter pathways.