DEPARTMENT OF Radiation Medicine

North Shore-LIJ CANCER INSTITUTE

# CNS Anatomy & Contouring

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# Disclosure

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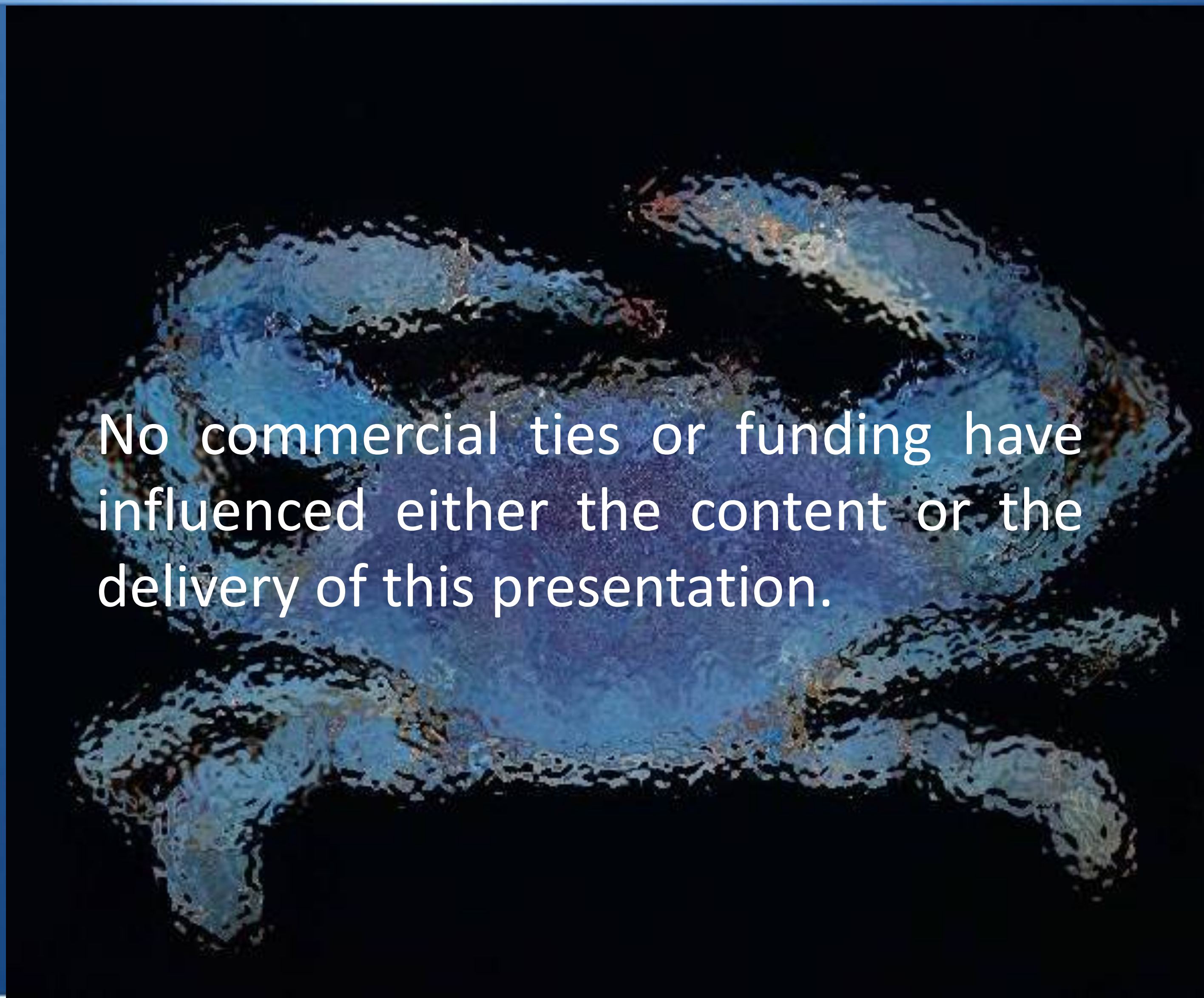

No commercial ties or funding have influenced either the content or the delivery of this presentation.

# Topics to be Covered

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

# Anatomy

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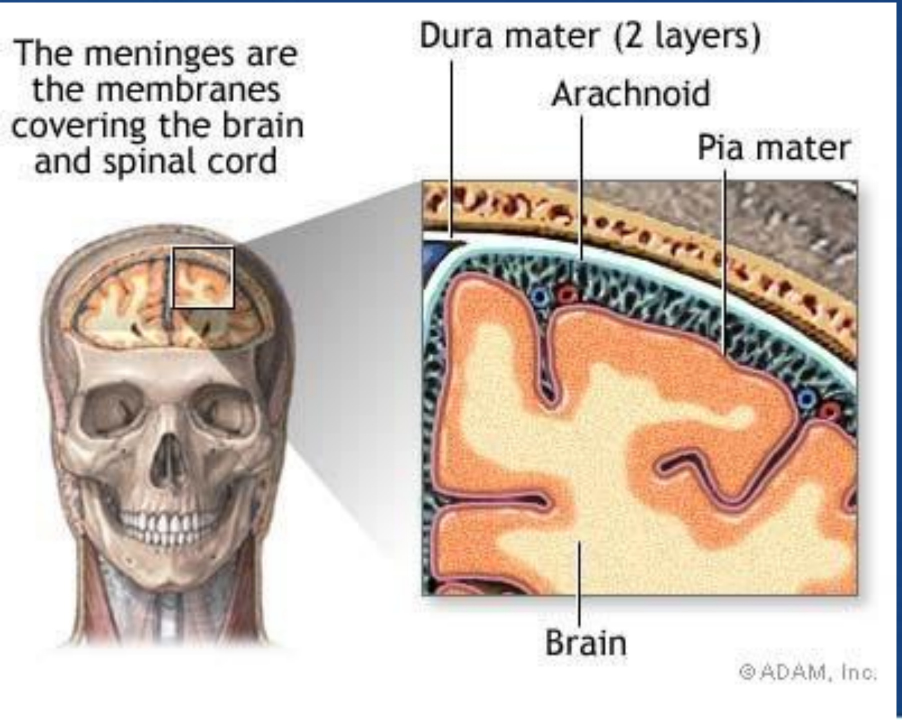
- The CNS consists of the brain and spinal cord
- The bony skull and spinal canal (formed by the vertebral bodies) confine the CNS within a series of membranes (meninges) that also contain the cerebrospinal fluid (CSF) surrounding the brain and spinal cord
- Nerves and blood vessels enter and exit the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



# Anatomy

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- 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

# Tumors Affecting the CNS



- 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

# Primary CNS Tumors—Extra-Axial *vs.* Intra-Axial

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- 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

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- 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

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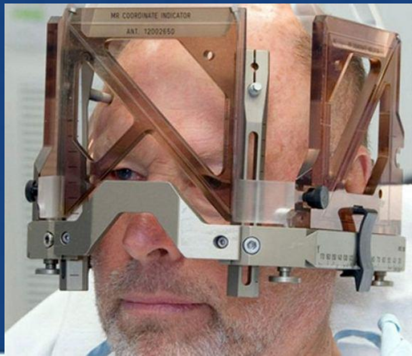
- External beam radiotherapy
  - Whole brain radiotherapy
  - Partial brain radiotherapy
  - Craniospinal radiotherapy
  - Stereotactic Radiosurgery
- Brachytherapy
  - Temporary
  - Permanent

- 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

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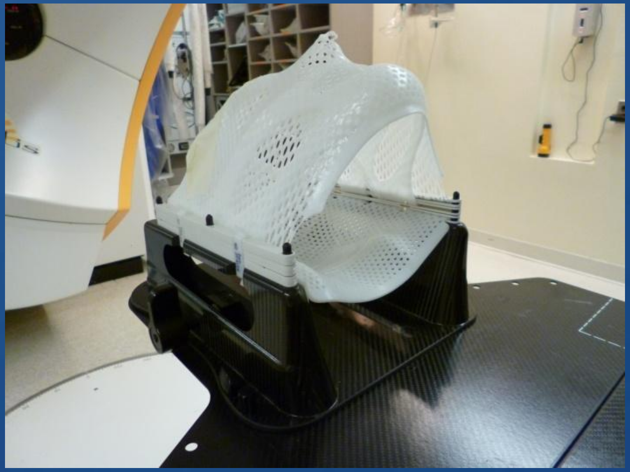
- Two thermoplastic layers
- Custom thermoplastic head support
- Spacers needed to adjust ‘tightness’ of mask
- Stereotactic accuracy possible



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

# Frameless Immobilization

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- 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

# How Accurate Can Frameless Be?

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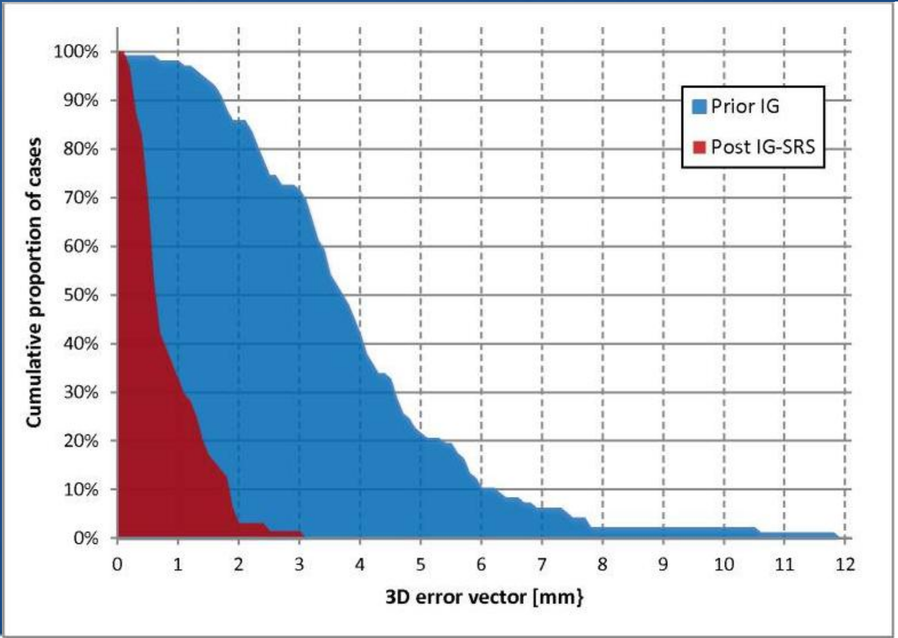
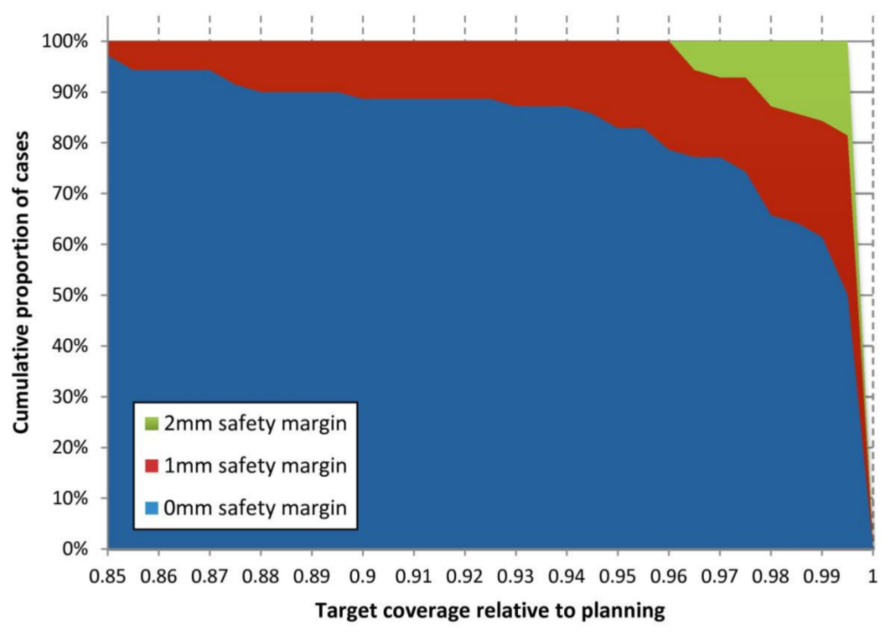
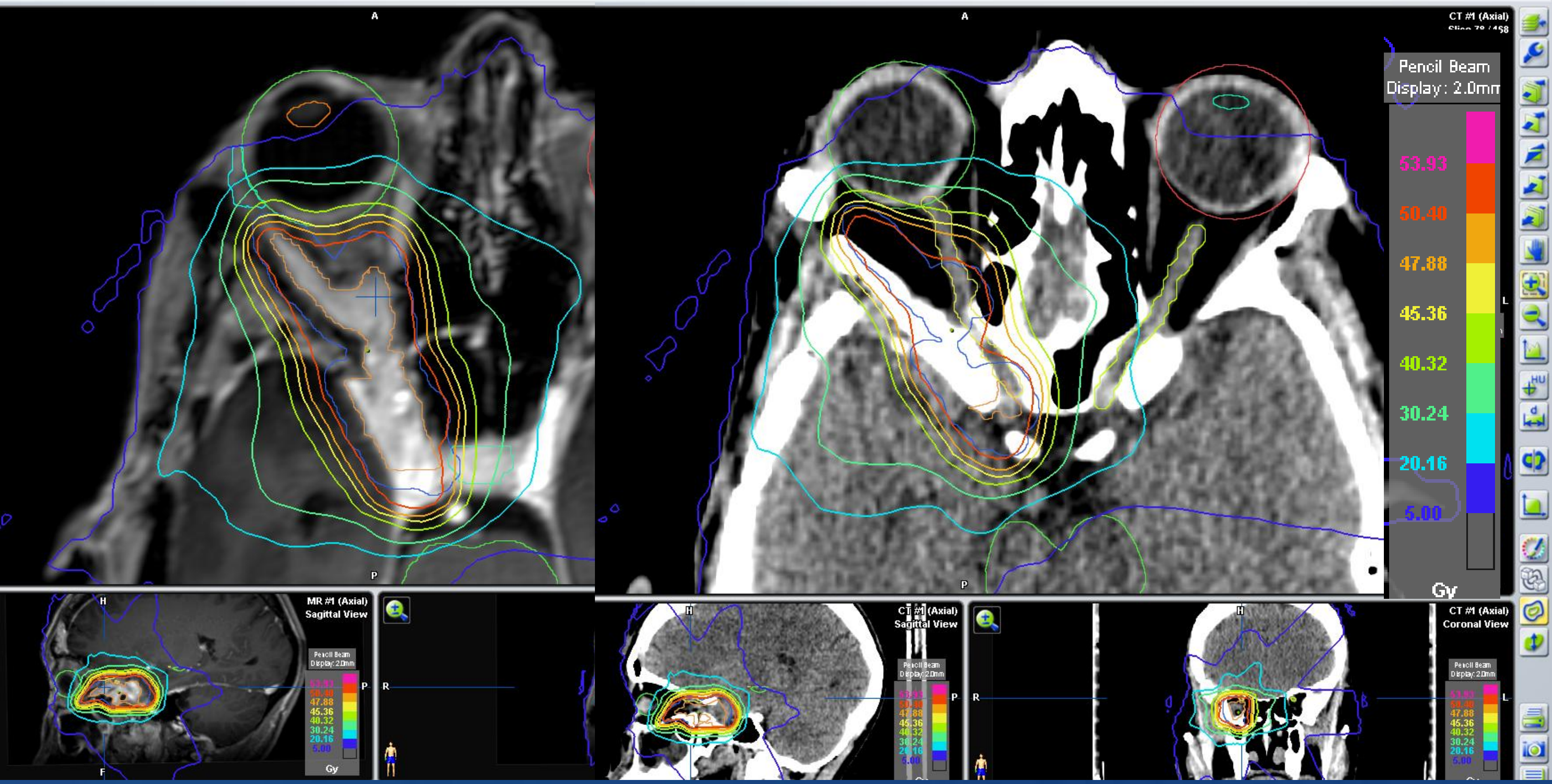
- Guckenberger et al. *Dosimetric consequences of translational and rotational errors in frame-less image-guided radiosurgery.* http://www.ro-journal.com/content/7/1/63
- CBCT & 6 DOF table used pre & post SRS to check setup accuracy
- Pre-IG errors were 3.9 mm ± 1.7 mm (3D vector) & maximum rotational 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.



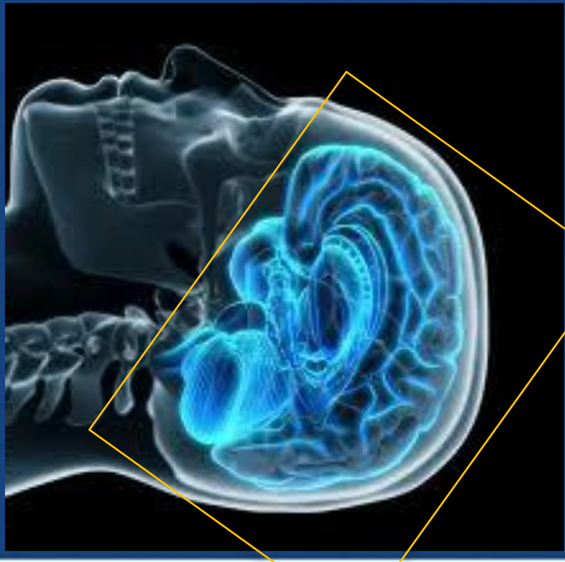



# Fractionated Stereotactic IMRT



# 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



# WBRT--Innovations

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- Innovations may appear to be superior, but assessments proving value are still pending

Int. J. Radiation Oncology Biol. Phys., Vol. 68, No. 2, pp. 621–631, 2007

0360-3016/07/$–see front matter

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doi:10.1016/j.ijrobp.2006.12.004

PHYSICS CONTRIBUTION

**A DOSIMETRIC EVALUATION OF CONVENTIONAL HELMET FIELD IRRADIATION VERSUS TWO-FIELD INTENSITY-MODULATED RADIOTHERAPY TECHNIQUE**

JAMES B. YU, M.D.,* STEPHEN L. SHIAO, B.S., AND JONATHAN P. S. KNISELY, M.D., F.R.C.P.C.*†

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Int. J. Radiation Oncology Biol. Phys., Vol. 78, No. 4, pp. 1244–1252, 2010

0360-3016/$–see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2010.01.039

PHYSICS CONTRIBUTION

HIPPOCAMPAL-SPARING WHOLE-BRAIN RADIOTHERAPY: A "HOW-TO" TECHNIQUE USING HELICAL TOMOTHERAPY AND LINEAR ACCELERATOR–BASED INTENSITY-MODULATED RADIOTHERAPY

VINAI GONDI, M.D.,* RANJINI TOLAKANAHALLI, M.S.,y MINESH P. MEHTA, M.D.,* DINESH TEWATIA, M.S.,*y HOWARD ROWLEY, M.D.,z JOHN S. KUO, M.D., PH.D.,*x DEEPAK KHUNTIA, M.D.,* AND WOLFGANG A. TOMÉ, PH.D.*y

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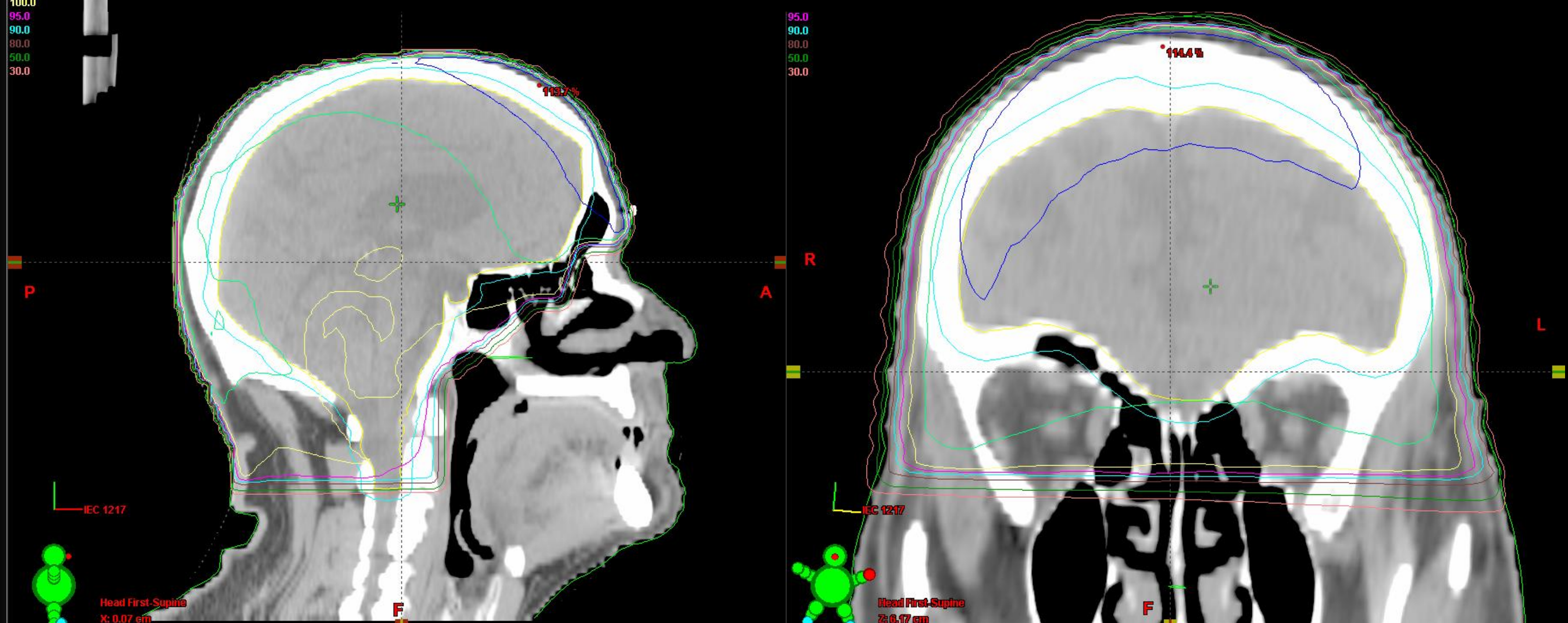
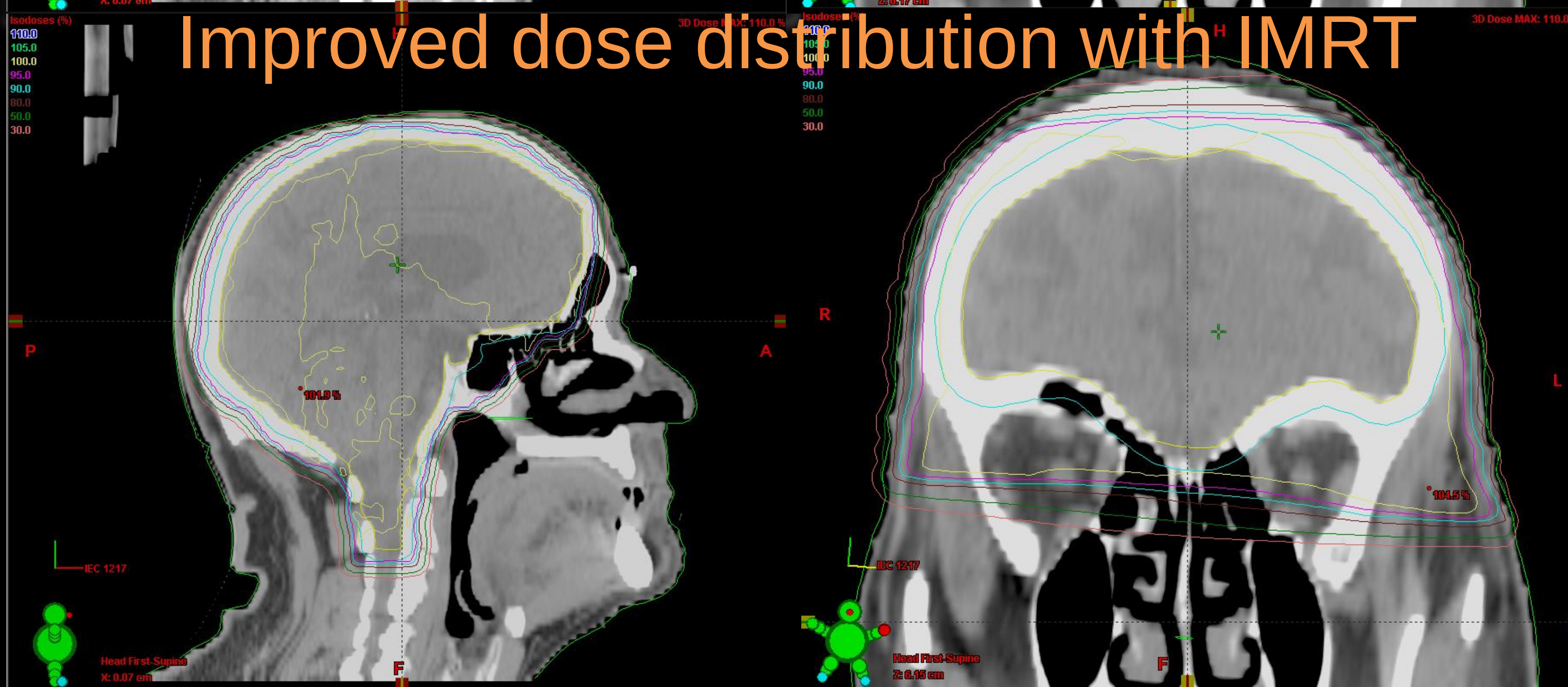
# Cranial Irradiation—WBRT vs. IMRT



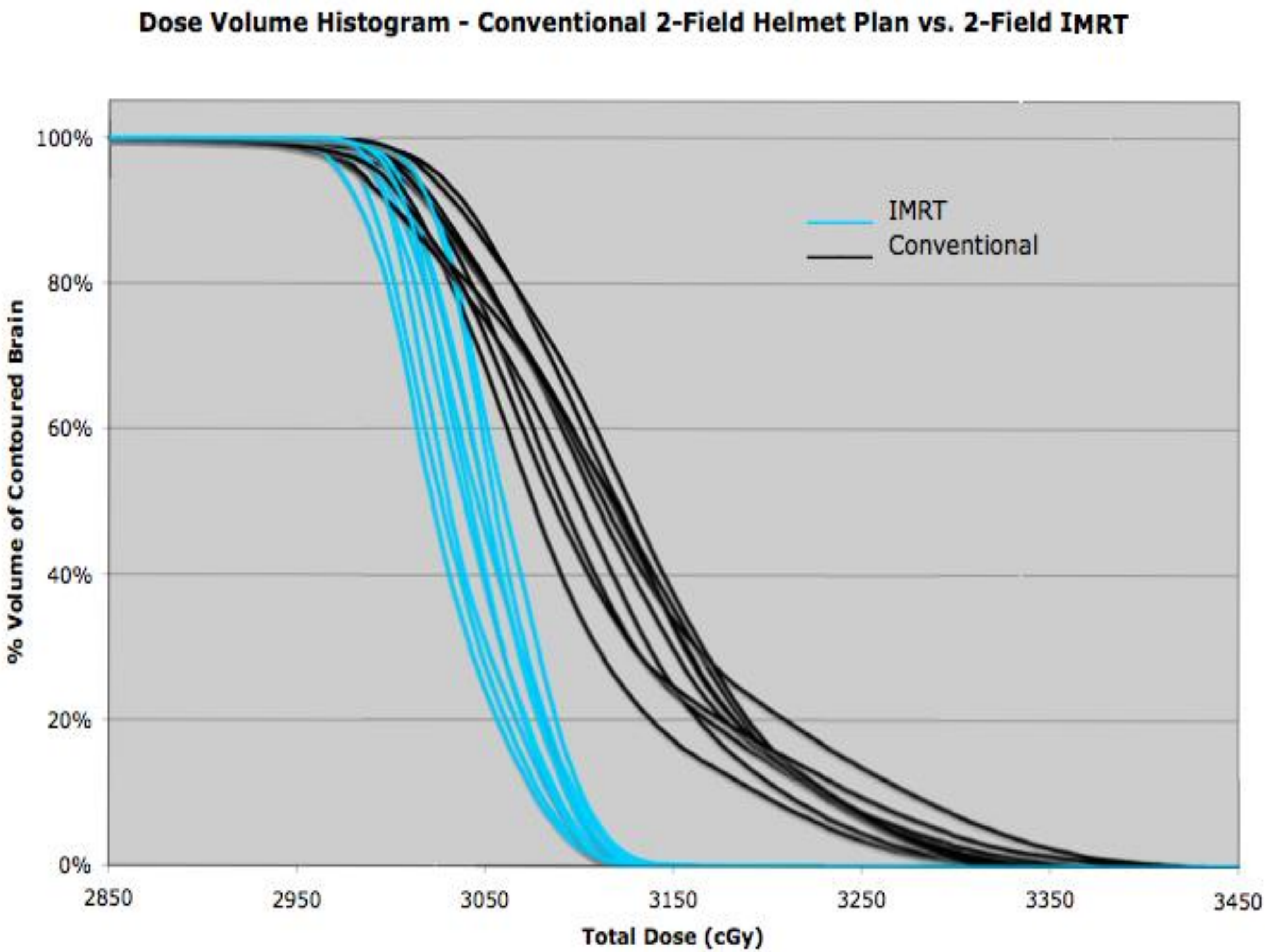

# Improved dose distribution with IMRT



# Cranial Irradiation—WBRT vs. IMRT

| | Hot Spot (Gy) | | % Contoured brain volume > 105% prescribed dose | | % Contoured brain volume > 110% prescribed dose | | % Contoured brain volume > 98% prescribed dose | |
|---|---|---|---|---|---|---|---|---|
| Pt # | EBRT | IMRT | EBRT | IMRT | EBRT | IMRT | EBRT | IMRT |
| **1** | **33.67** | **31.38** | **33.30%** | **0.00%** | **2.20%** | **0.00%** | **99.24%** | **99.98%** |
| **2** | **33.95** | **31.03** | **35.35%** | **0.02%** | **2.05%** | **0.00%** | **99.86%** | **99.99%** |
| **3** | **33.73** | **31.62** | **23.76%** | **0.06%** | **2.88%** | **0.00%** | **99.71%** | **100.00%** |
| **4** | **33.46** | **31.71** | **29.70%** | **0.02%** | **1.18%** | **0.00%** | **99.30%** | **100.00%** |
| **5** | **34.50** | **31.56** | **33.80%** | **0.00%** | **7.09%** | **0.00%** | **99.12%** | **99.86%** |
| **6** | **33.96** | **31.50** | **32.85%** | **0.00%** | **1.50%** | **0.00%** | **99.80%** | **100.00%** |
| **7** | **33.36** | **31.71** | **17.29%** | **0.05%** | **0.60%** | **0.00%** | **99.84%** | **100.00%** |
| **8** | **33.49** | **32.10** | **24.59%** | **0.14%** | **0.88%** | **0.00%** | **98.93%** | **99.91%** |
| **9** | **33.46** | **31.35** | **37.32%** | **0.00%** | **1.18%** | **0.00%** | **99.82%** | **100.00%** |
| **10** | **34.23** | **31.50** | **24.63%** | **0.00%** | **4.30%** | **0.00%** | **99.12%** | **100.00%** |
| Mean | **33.78** | **31.63** | **29.26%** | **0.03%** | **2.39%** | **0.00%** | **99.47%** | **99.97%** |

# Cranial Irradiation—WBRT vs. IMRT



# Partial Brain Radiotherapy

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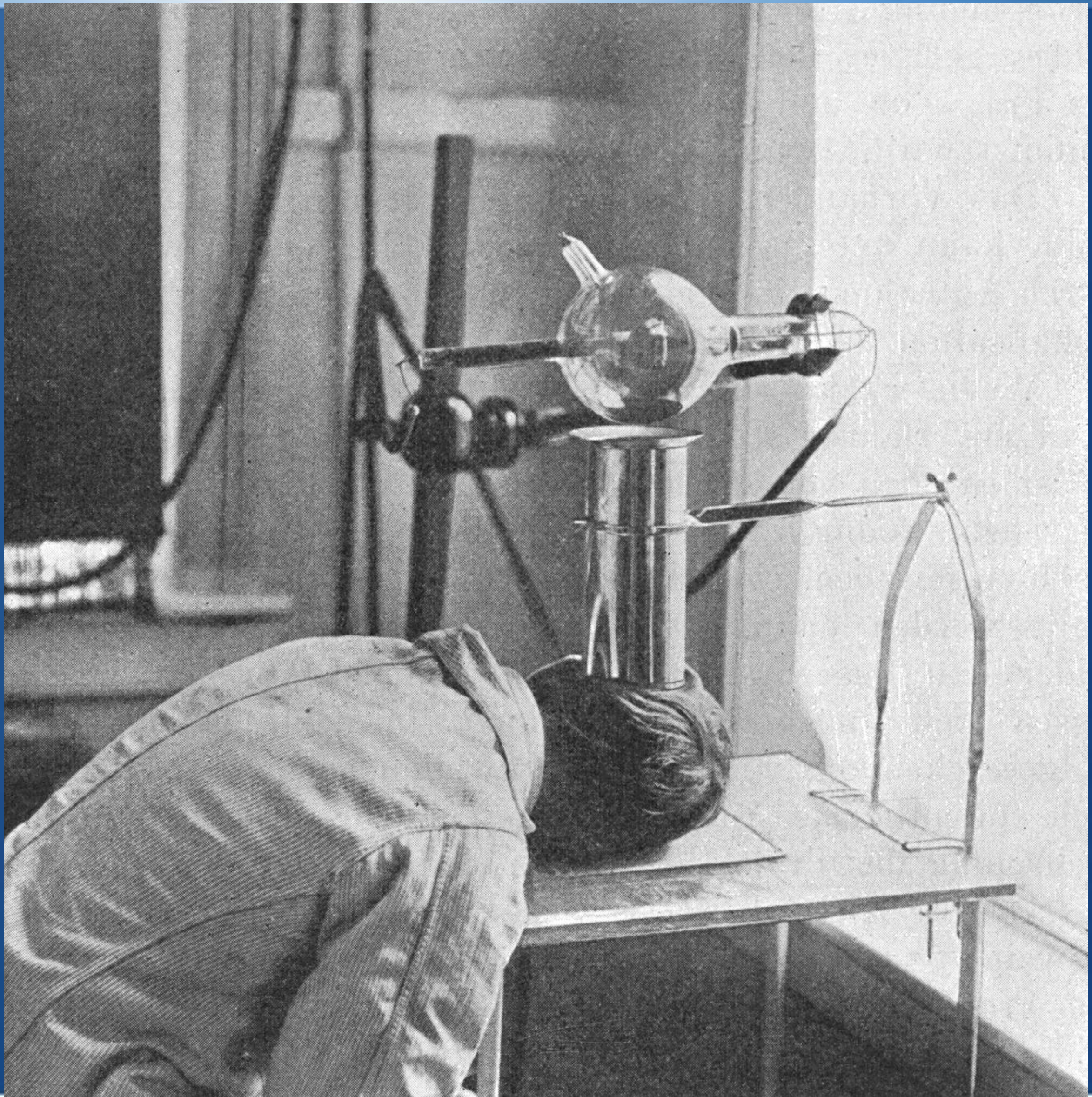

# Partial Brain IMRT DRR /Portal Film

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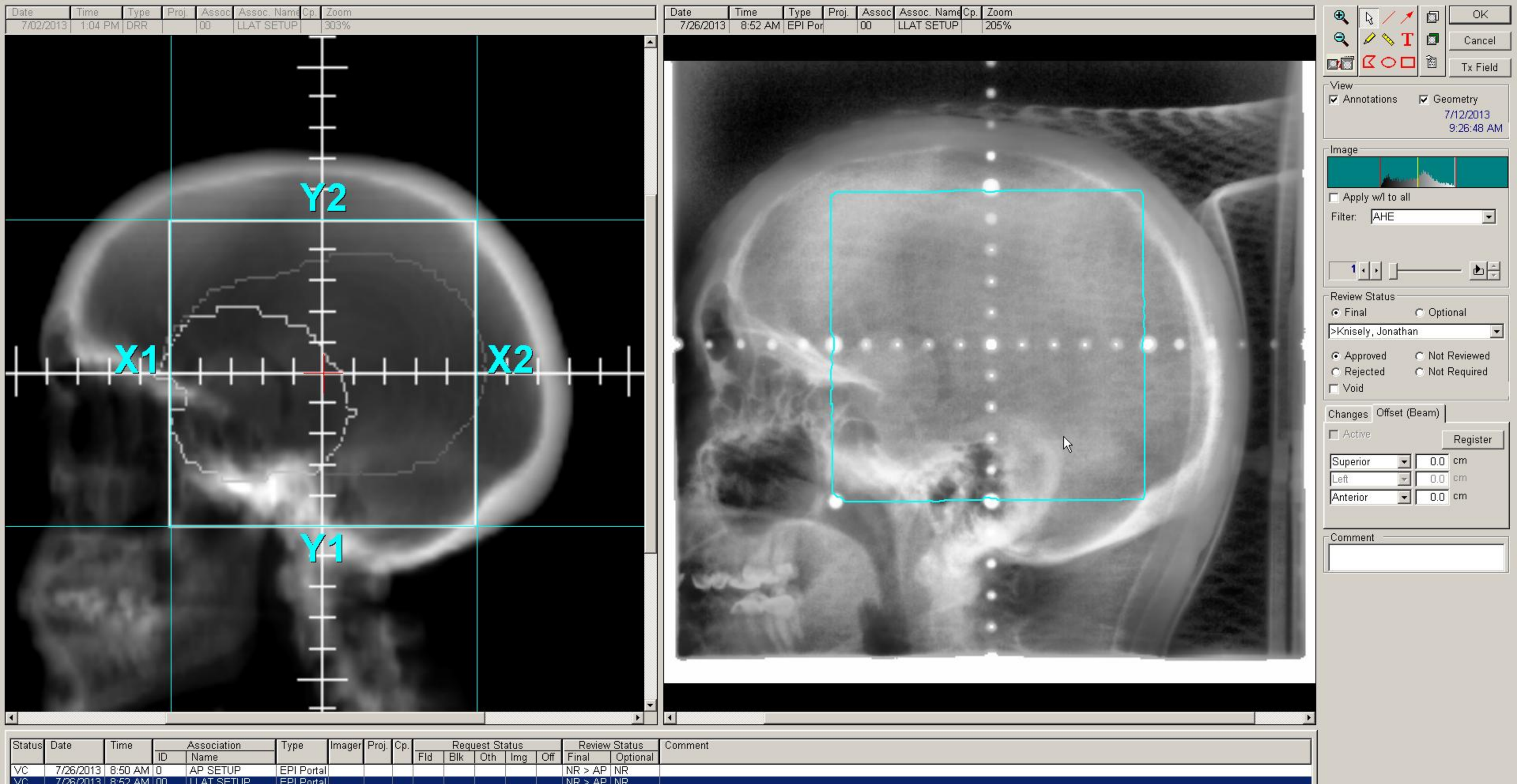
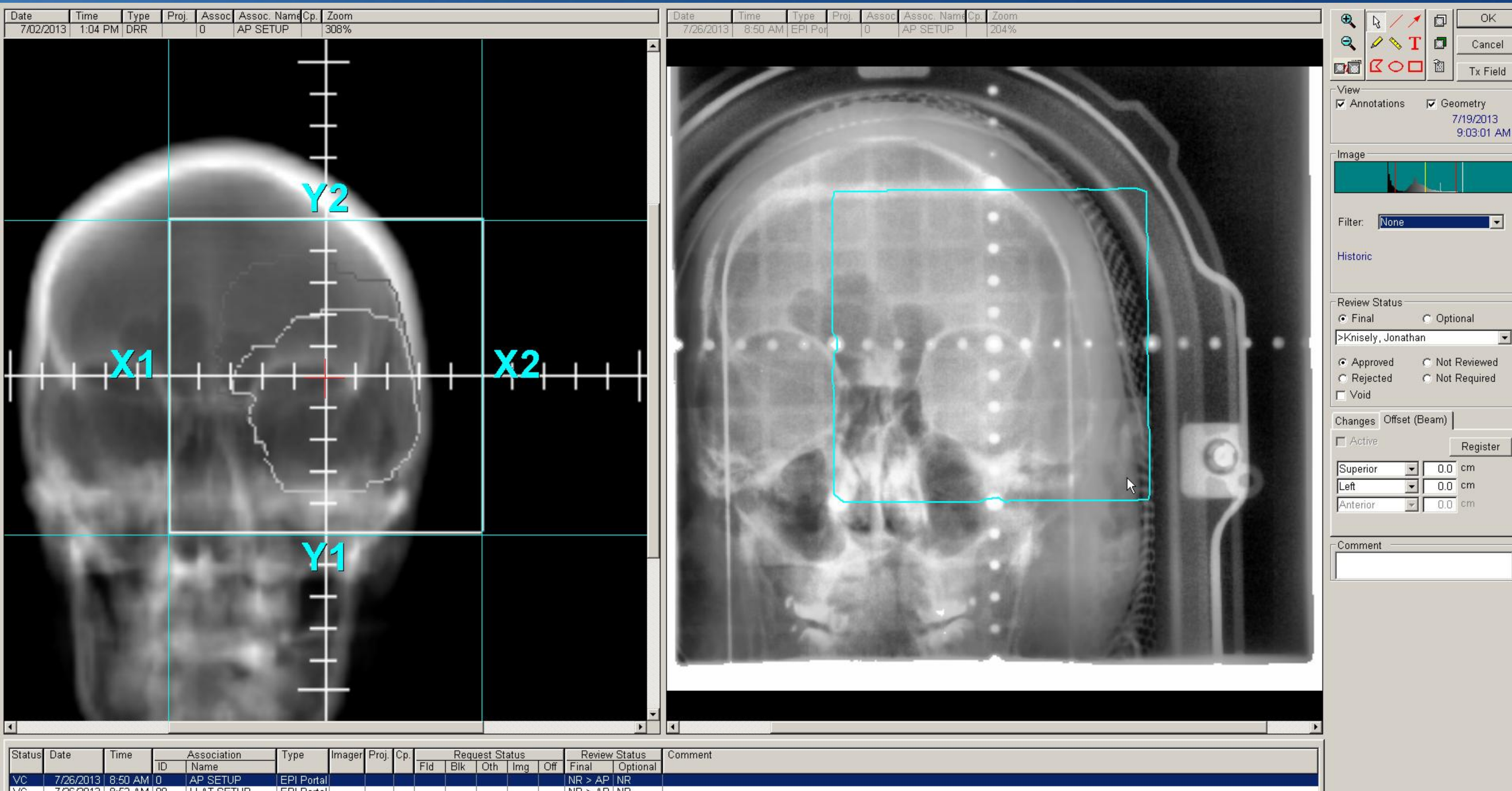
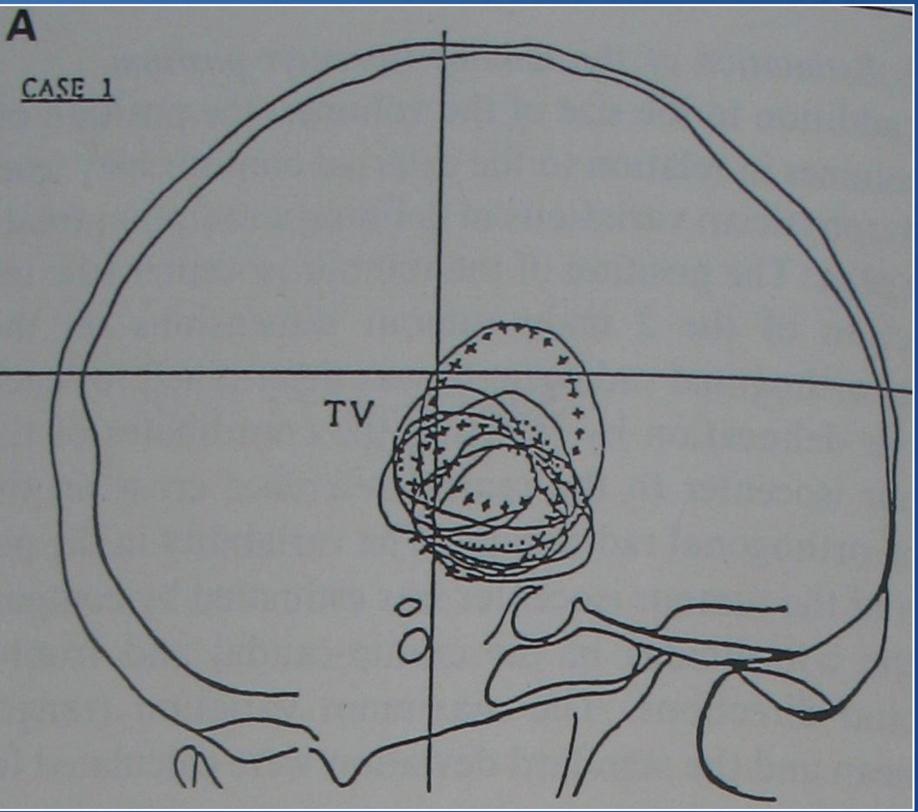
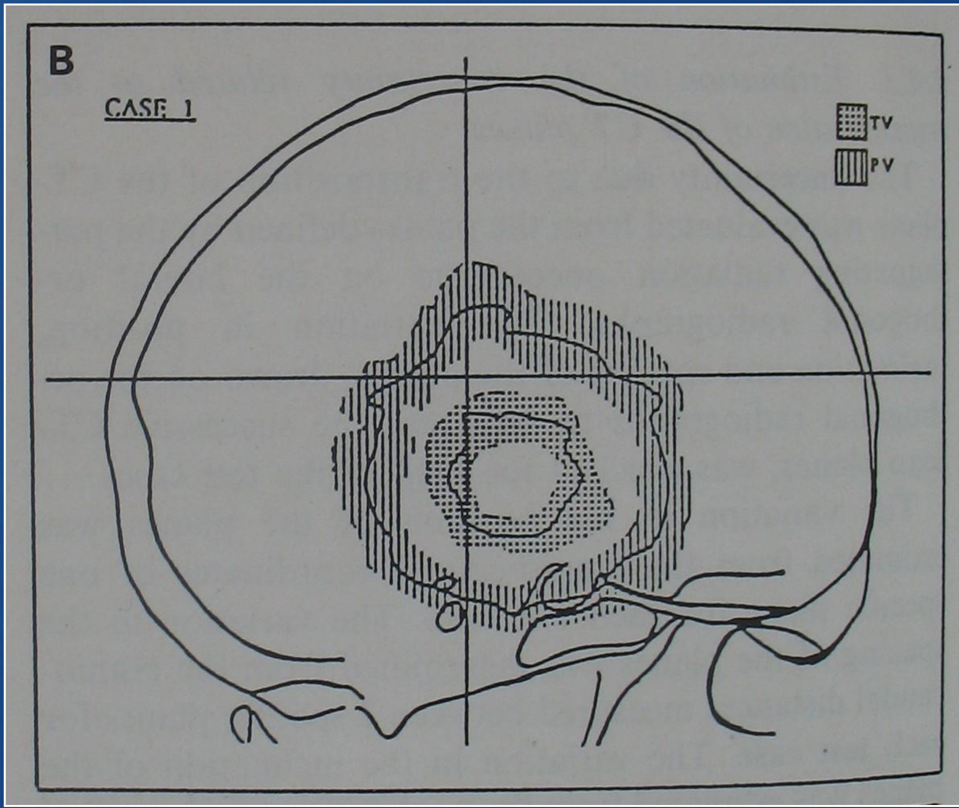


# Partial Brain IMRT DRR /Portal Film



# Imprecision in Manual Target Delineation




Leunens G, et al. Quality assessment of medical decision making in radiation oncology: variability in target volume delineation for brain tumours. Radiother Oncol 1993,29:169-75.

# 3D Rigid Image Registration

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**82** **AUTOMATIC THREE DIMENSIONAL CO-REGISTRATION OF DIAGNOSTIC MRI AND TREATMENT PLANNING CT FOR BRAIN TUMOR RADIOTHERAPY TREATMENT PLANNING**

Knisely JPS[1], Yue N[2], Chen Z[2], Nath R[1], Trumpore S[2], Duncan JS[1], Studholme C[1]

*Yale University School of Medicine, New Haven, CT, USA[1]; Yale-New Haven Hospital, New Haven, CT, USA[2]*

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

Int. J. Radiation Oncology Biol. Phys., Vol. 57, No. 4, pp. 1150–1158, 2003

0360-3016/03/$–see front matter

ELSEVIER

doi:10.1016/S0360-3016(03)01568-2

**PHYSICS CONTRIBUTION**

**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**

JAMES E. BOND, PH.D.,* VERNON SMITH, PH.D.,† NING J. YUE, PH.D.,* AND JONATHAN P. S. KNISELY, M.D., F.R.C.P.C.*

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# MR Imaging & Coregistration

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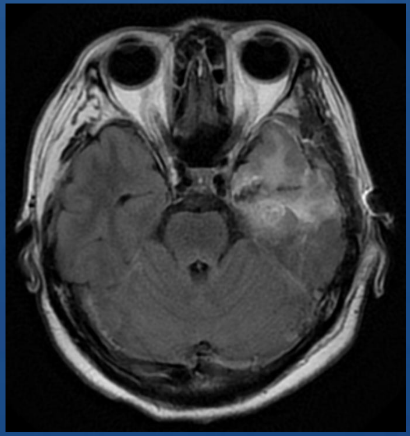
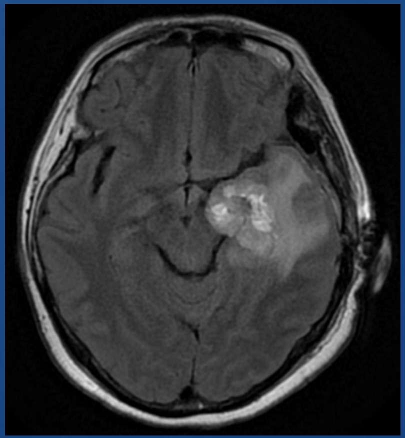
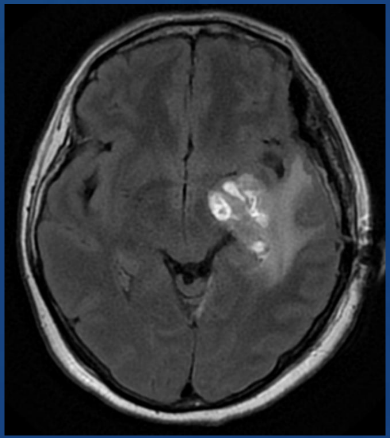
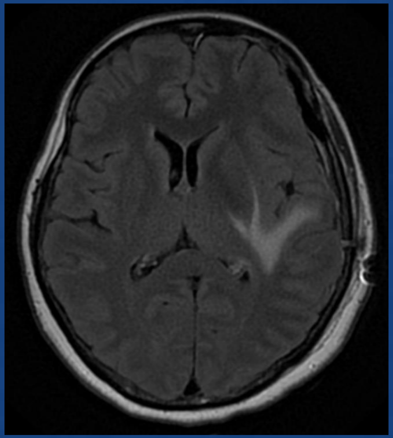
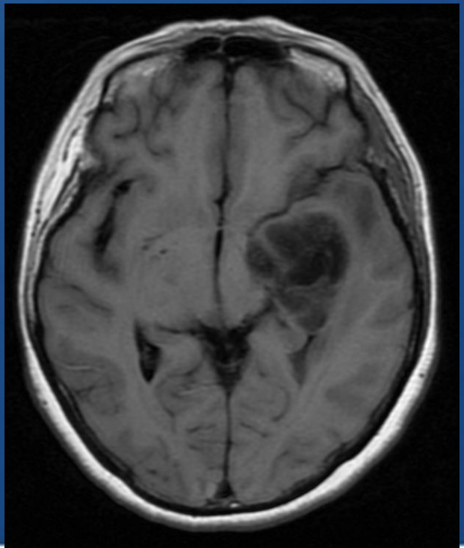
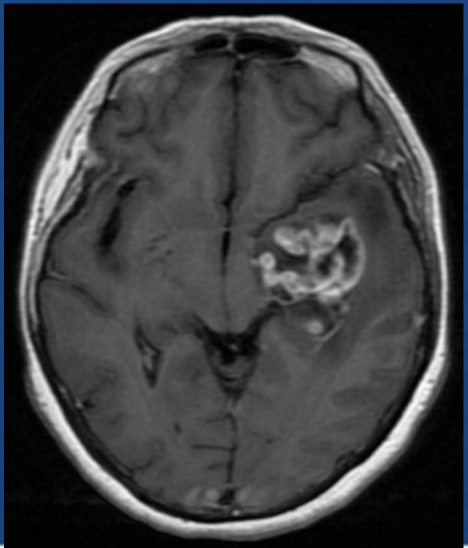
- T2 and FLAIR pulse sequences depict differences in the spin-spin (or $T_2$) relaxation time of various tissues within the body
- In T2 and FLAIR pulse sequences, water is bright, and clearly show tumor-associated edema for target contouring (usually only for infiltrative tumors like gliomas)

# MR Imaging & Coregistration

- 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





# MR Imaging & Coregistration

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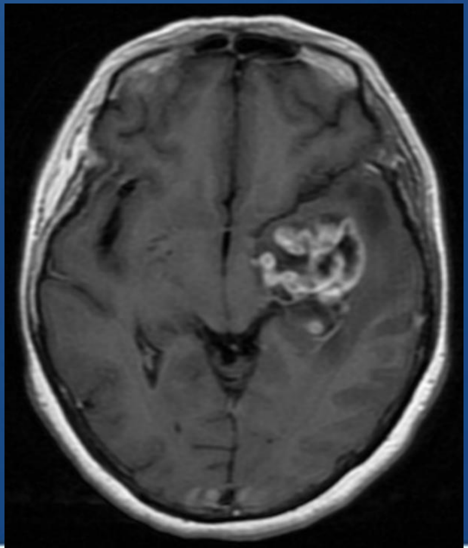
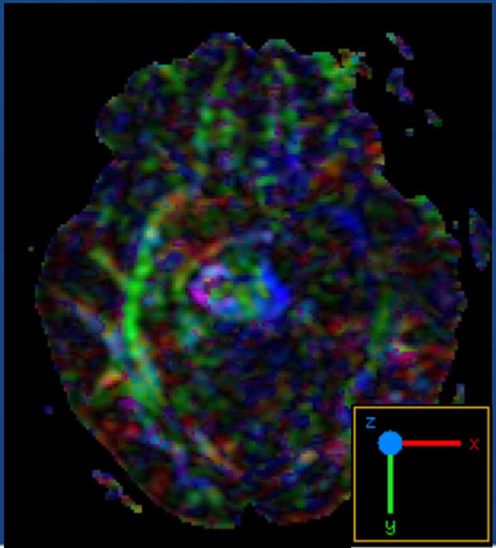
- Diffusion MRI measures the diffusion of water molecules in biological tissues
- The fractional anisotropy in each direction in each voxel can be calculated to make brain maps of fiber directions to examine the connectivity of different regions in the brain





# Non-Coplanar or Coplanar?

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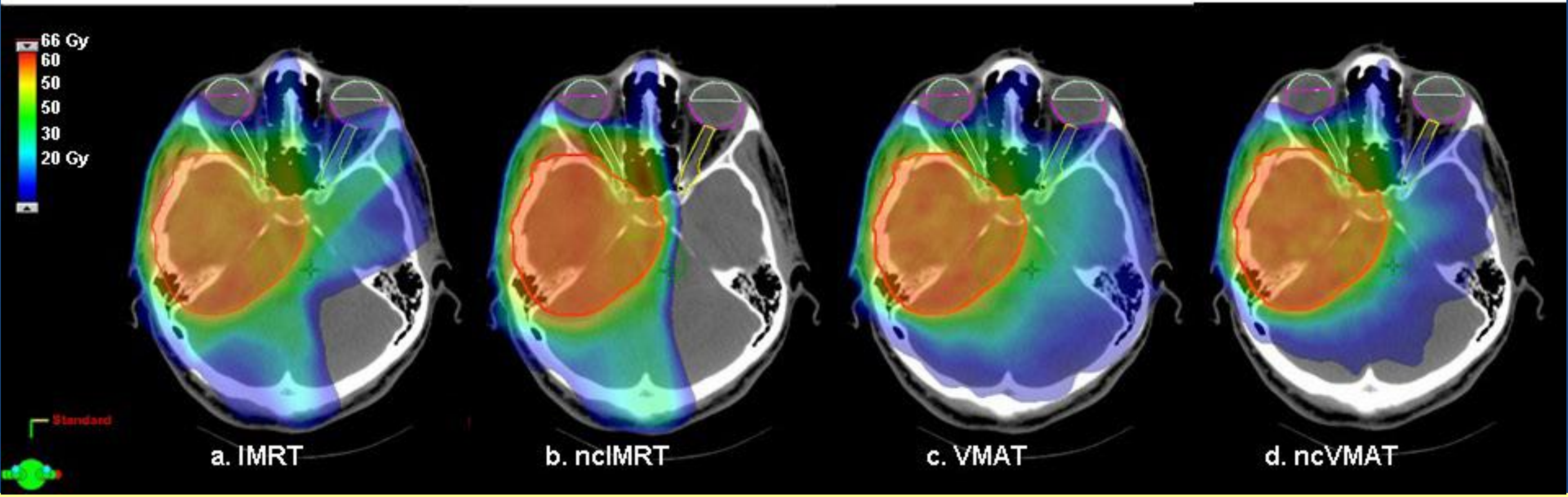
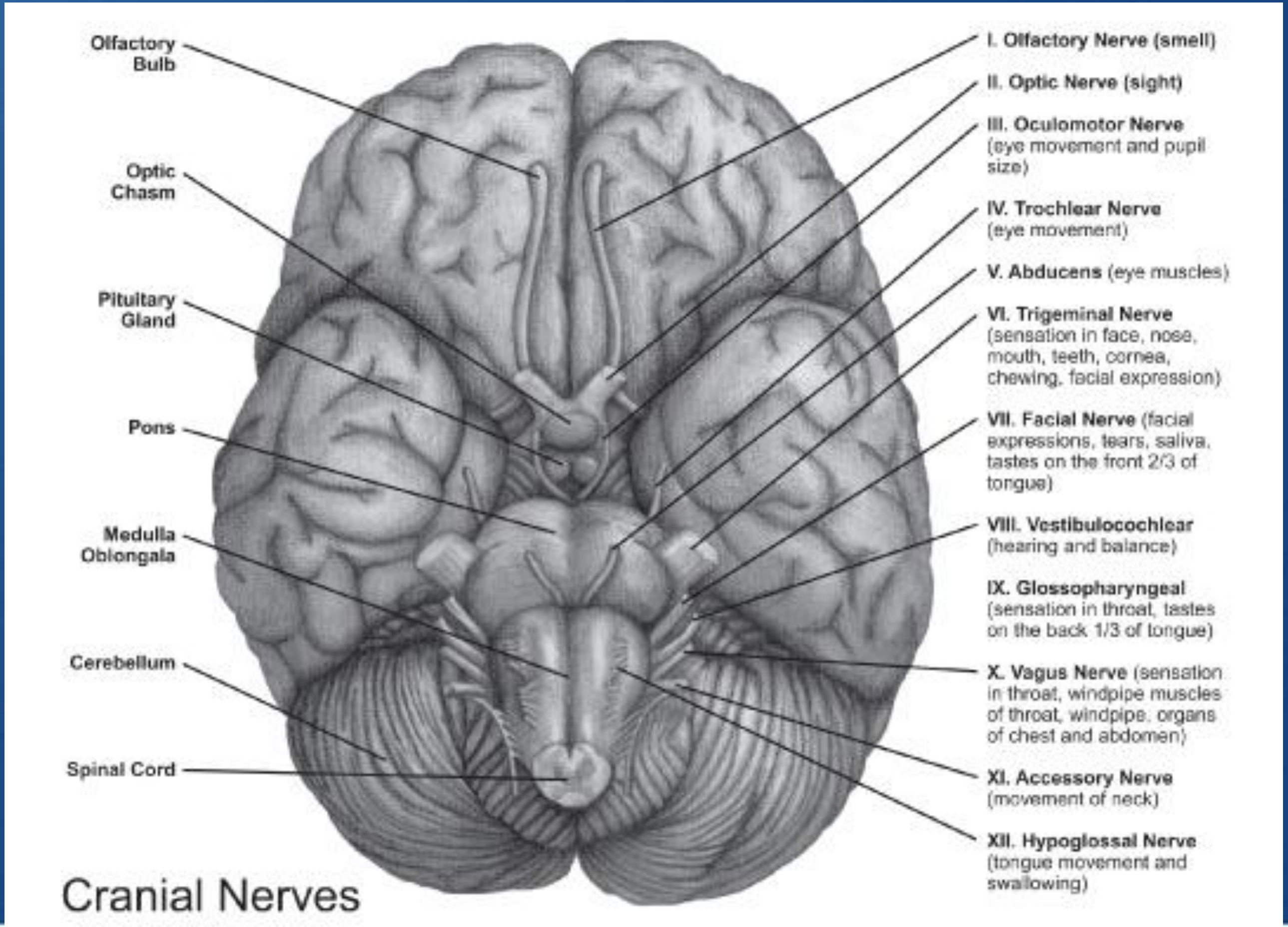
- Coplanar versus noncoplanar intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) treatment planning for fronto-temporal high-grade glioma*




V. Panet-Raymond *et al*. JACMP 13(4):44-53;2012.

# Cranial Nerves

Provide sensory input, and control muscles, glands, viscera, immune modulation



# Organs at Risk

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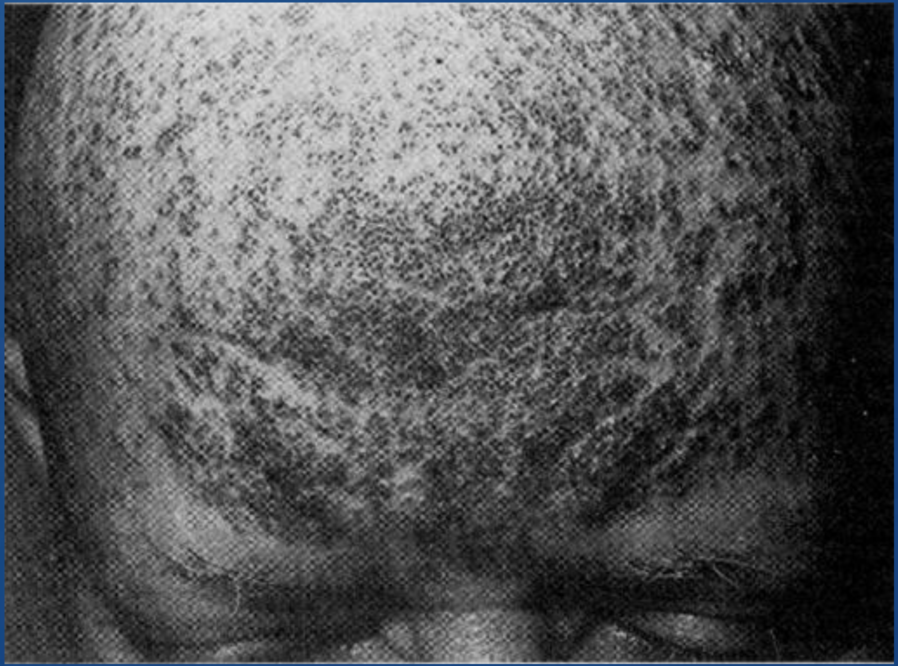
- Potential organs at risk in CNS radiotherapy include:
  - Scalp
  - Lenses
  - Retinae
  - Lacrimal Glands
  - Optic Nerves, Chiasm, and Tracts
  - Pituitary
  - Cochlae
  - Hippocampi
  - Brainstem
  - Cervical Spinal Cord
- There are different dose-limiting toxicities for different endpoints in different organs

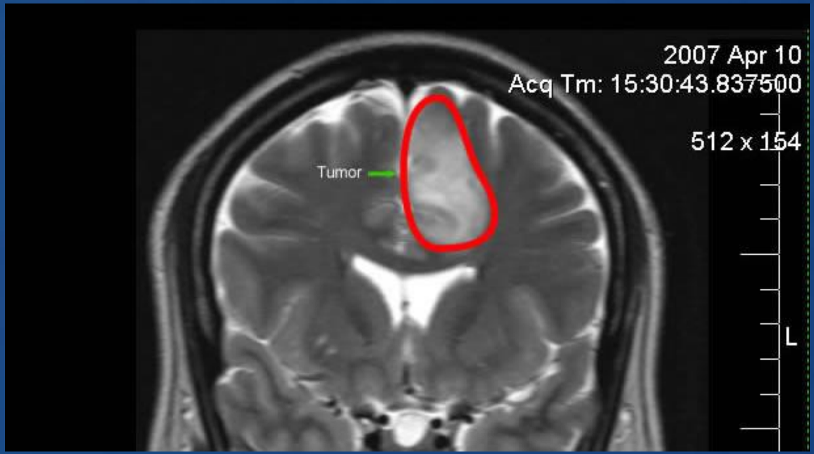
# Scalp Toxicity

- 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

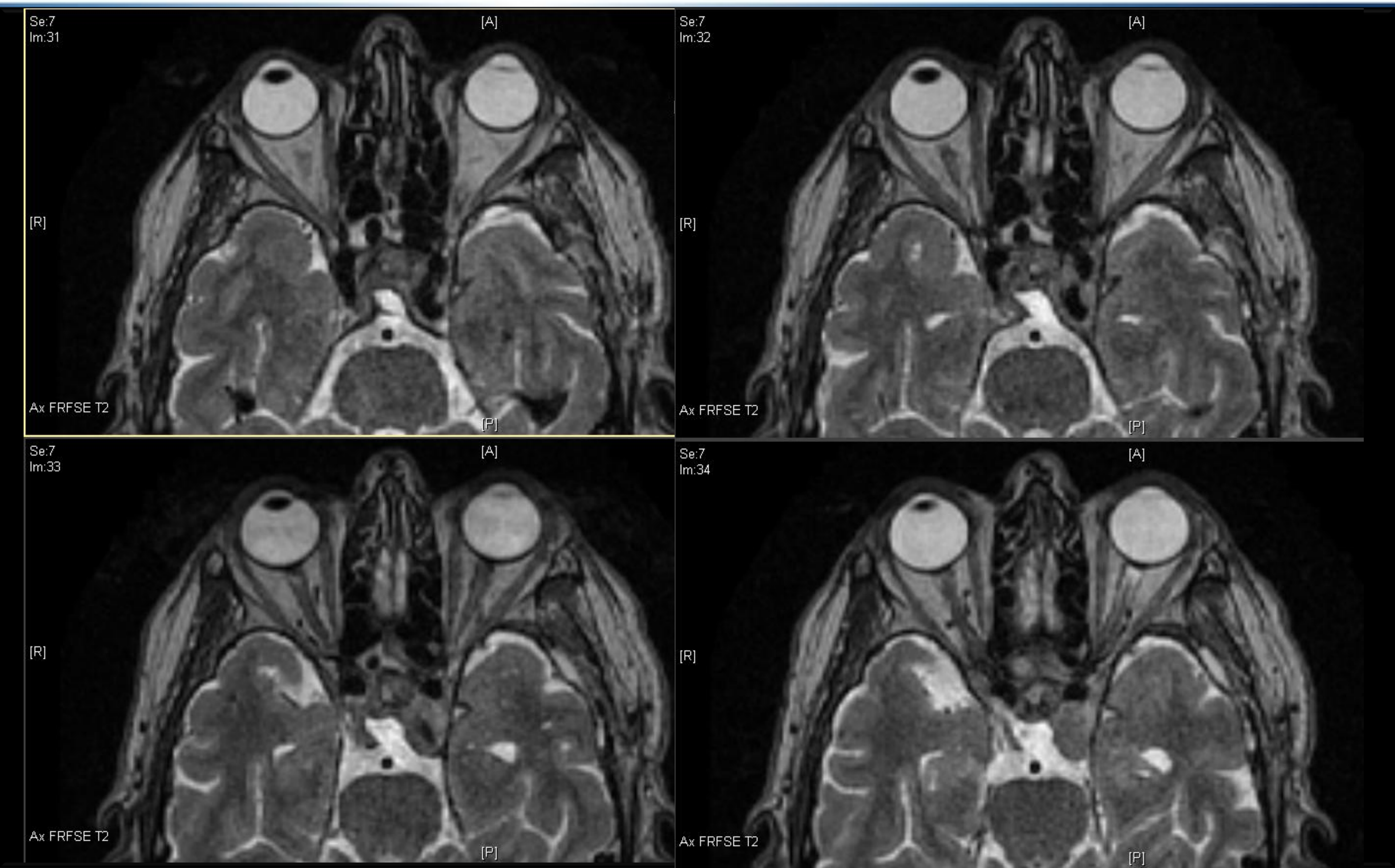
- Anaplastic Astrocytoma
- Resected at Mayo Clinic
- 60 Gy partial brain XRT
- Delivered in Florida





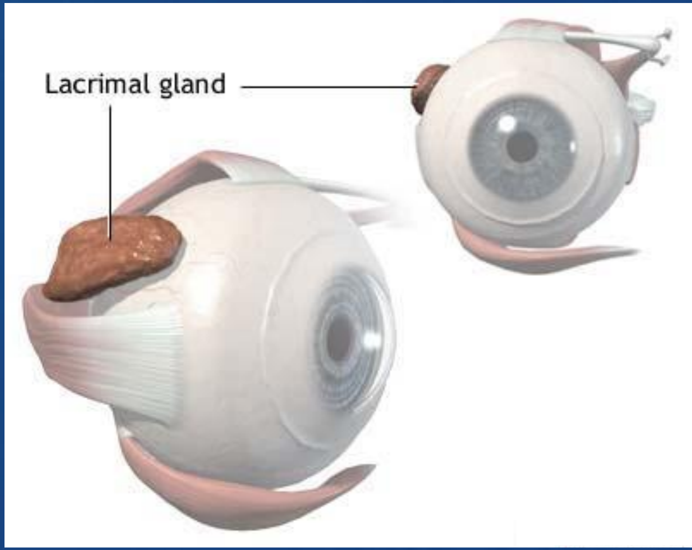
http://especiallyheather.com/2008/06/20/so-good-to-be-home/

# Pay Attention to the Optics



# Pay Attention to the Optics

- Lacrimal 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

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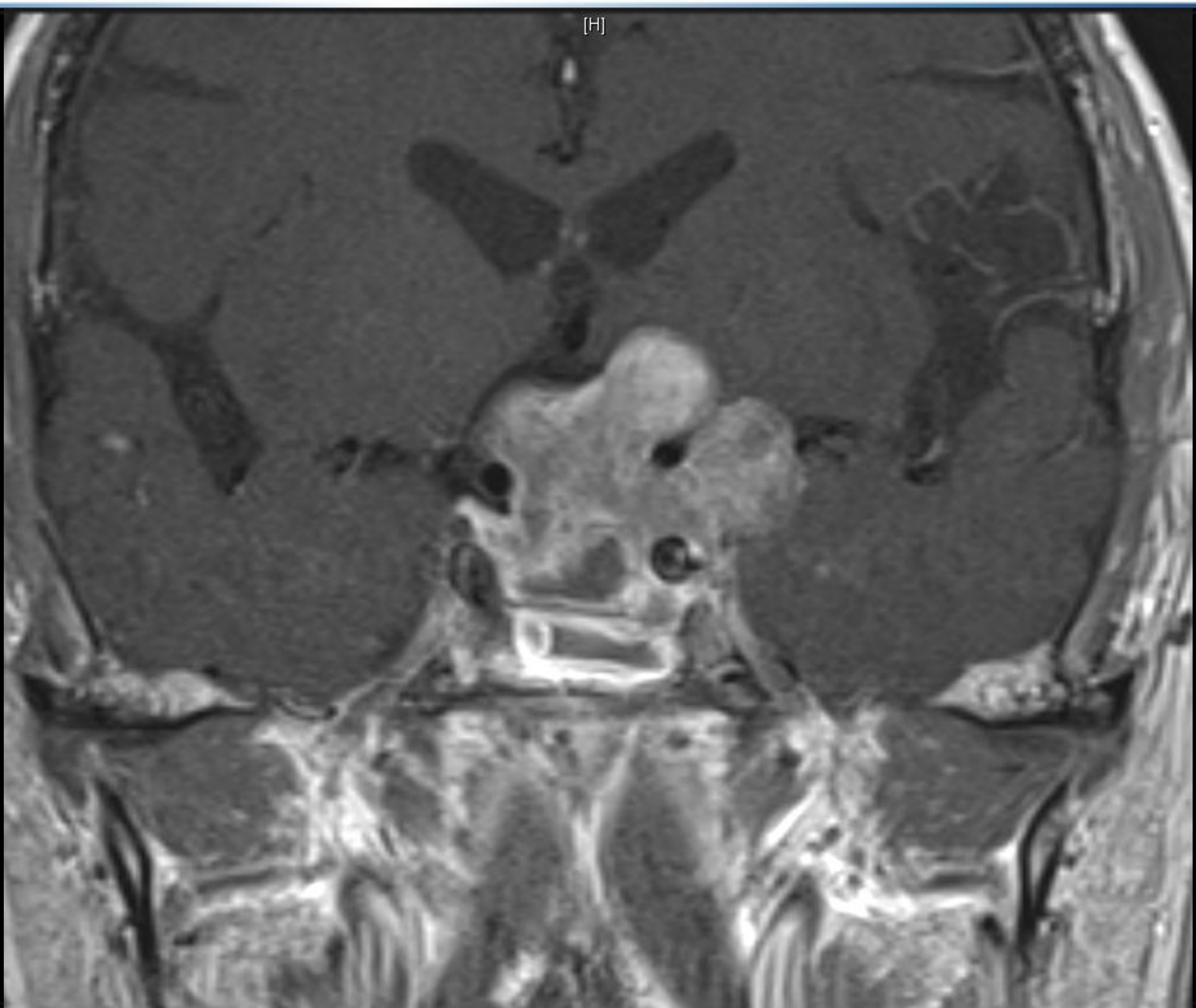
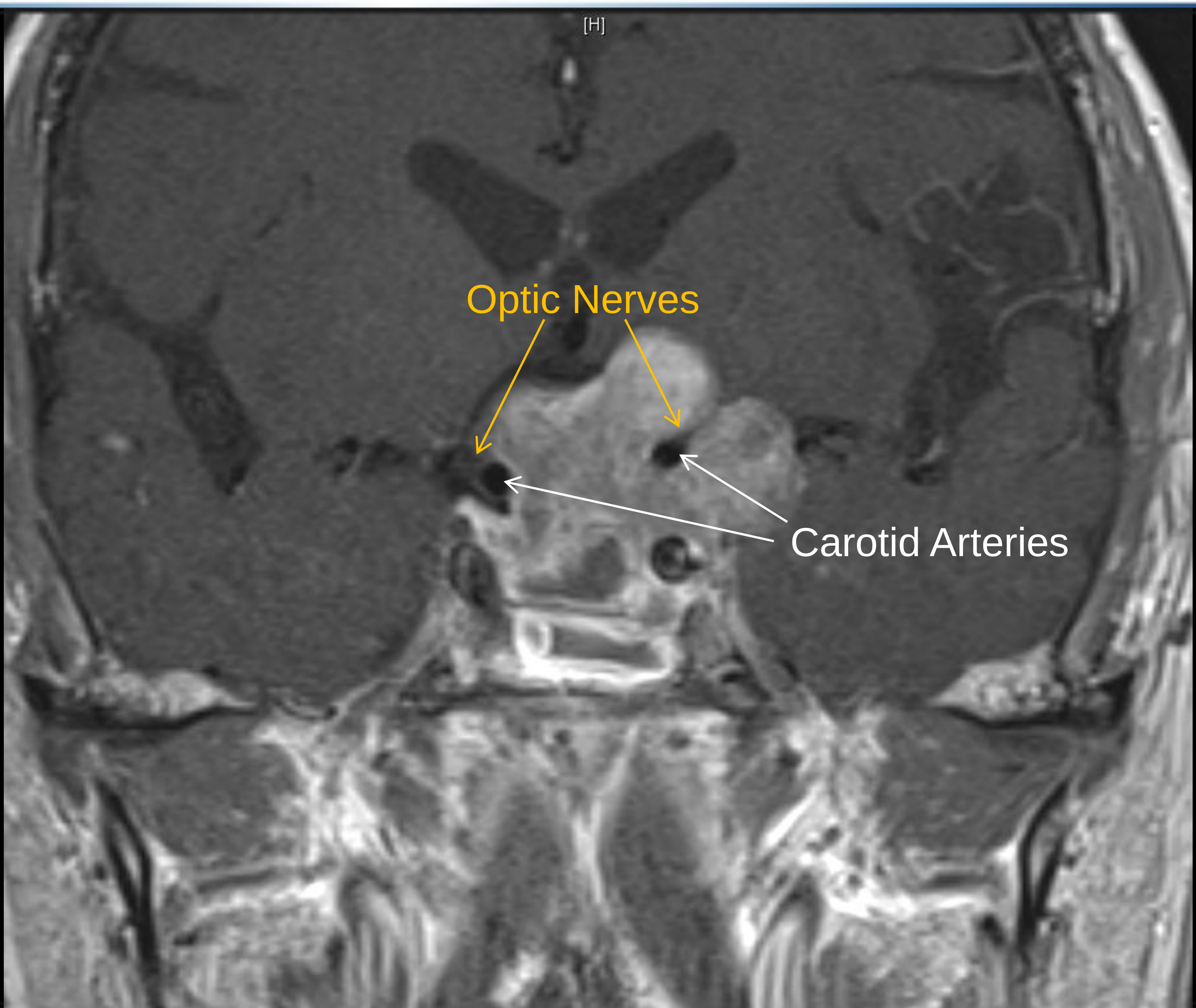
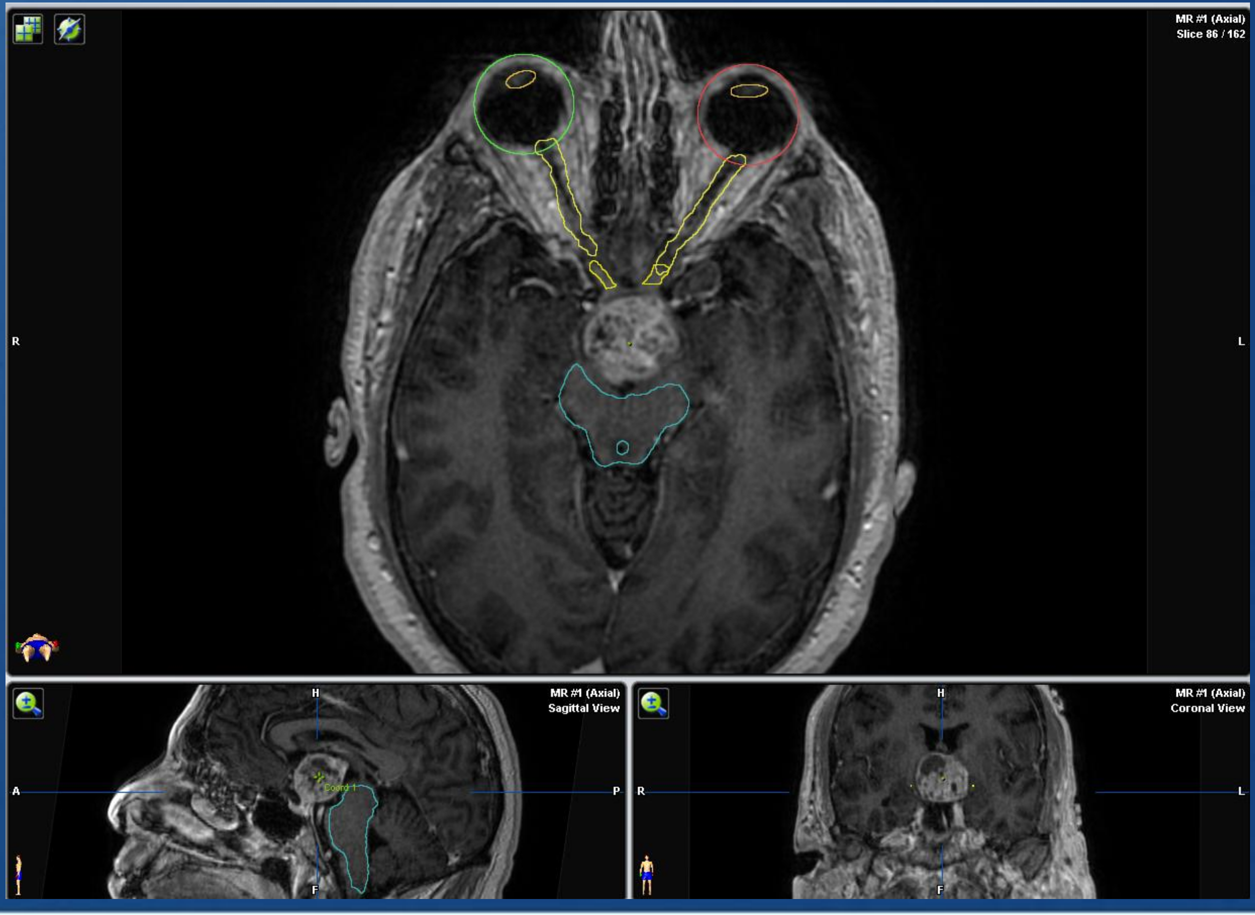


# Pay Attention to the Optics



# Optic Chiasm

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



# Optic Chiasm

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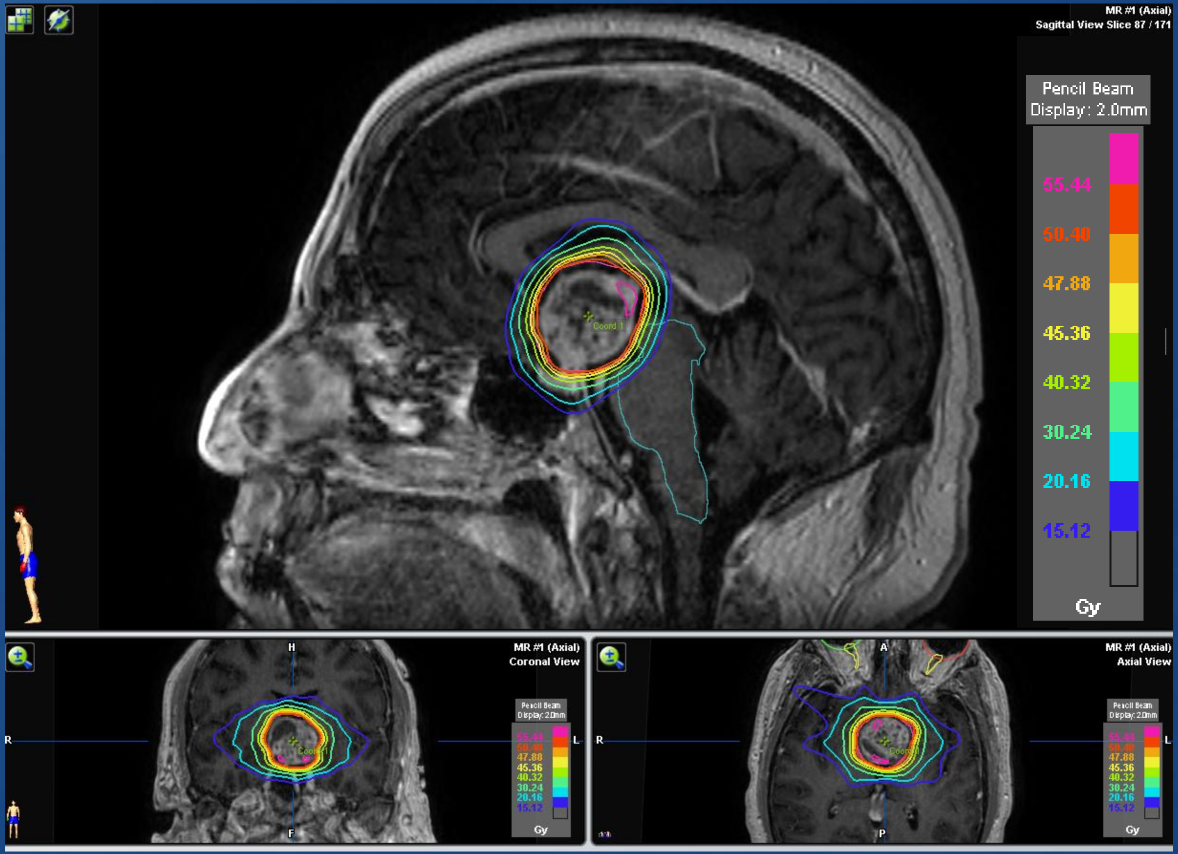
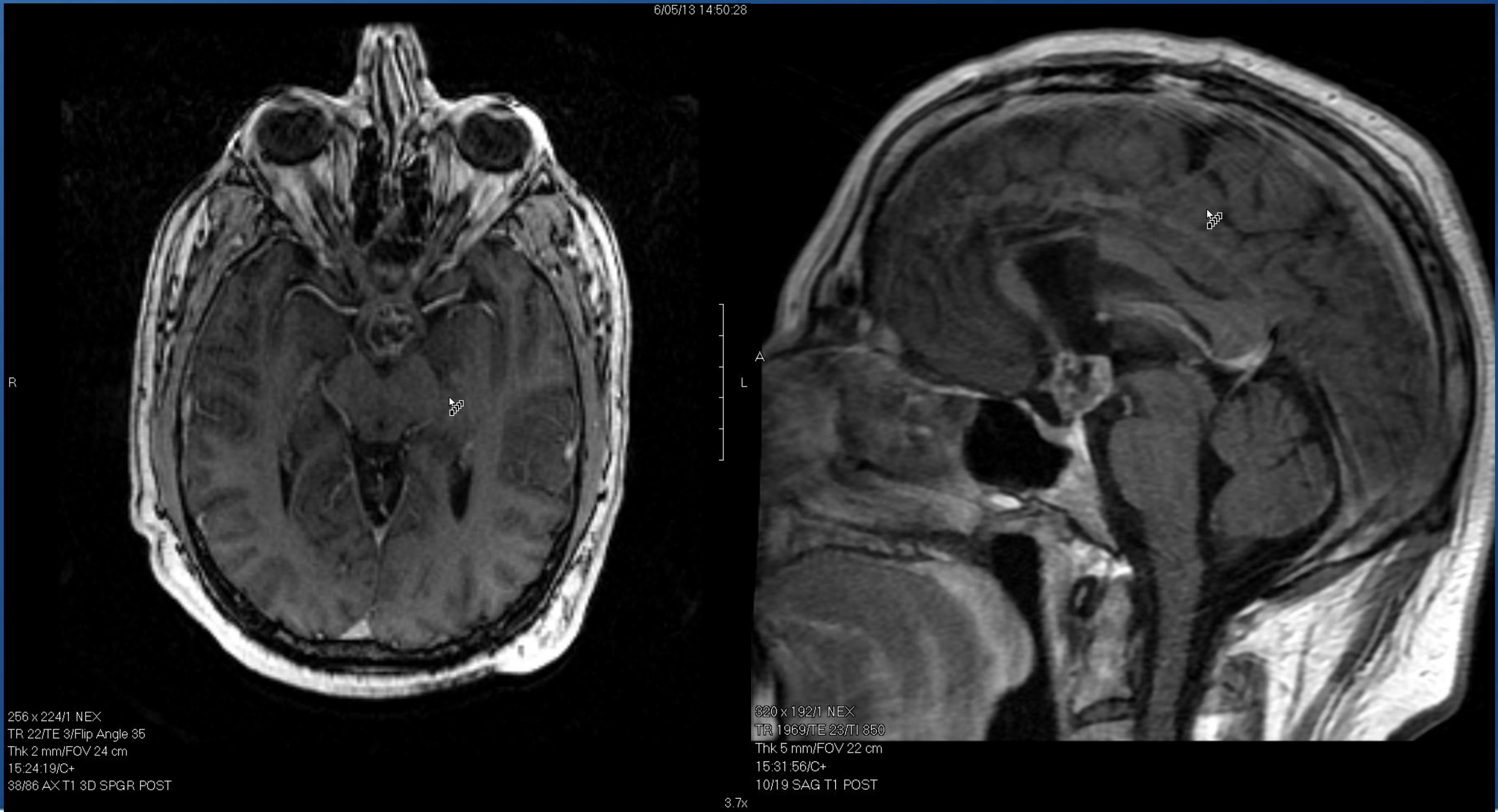
- 10 field IMRT plan, 6 MV photons, with daily stereotactic setup with kV image matching
- Hot spots (56.9 Gy $d_{max}$) are remote from optic apparatus



# Optic Chiasm

- 6 weeks follow-up MRI of craniopharyngioma
- Visual fields have returned to normal



# Cochlea—Where the Heck is it?

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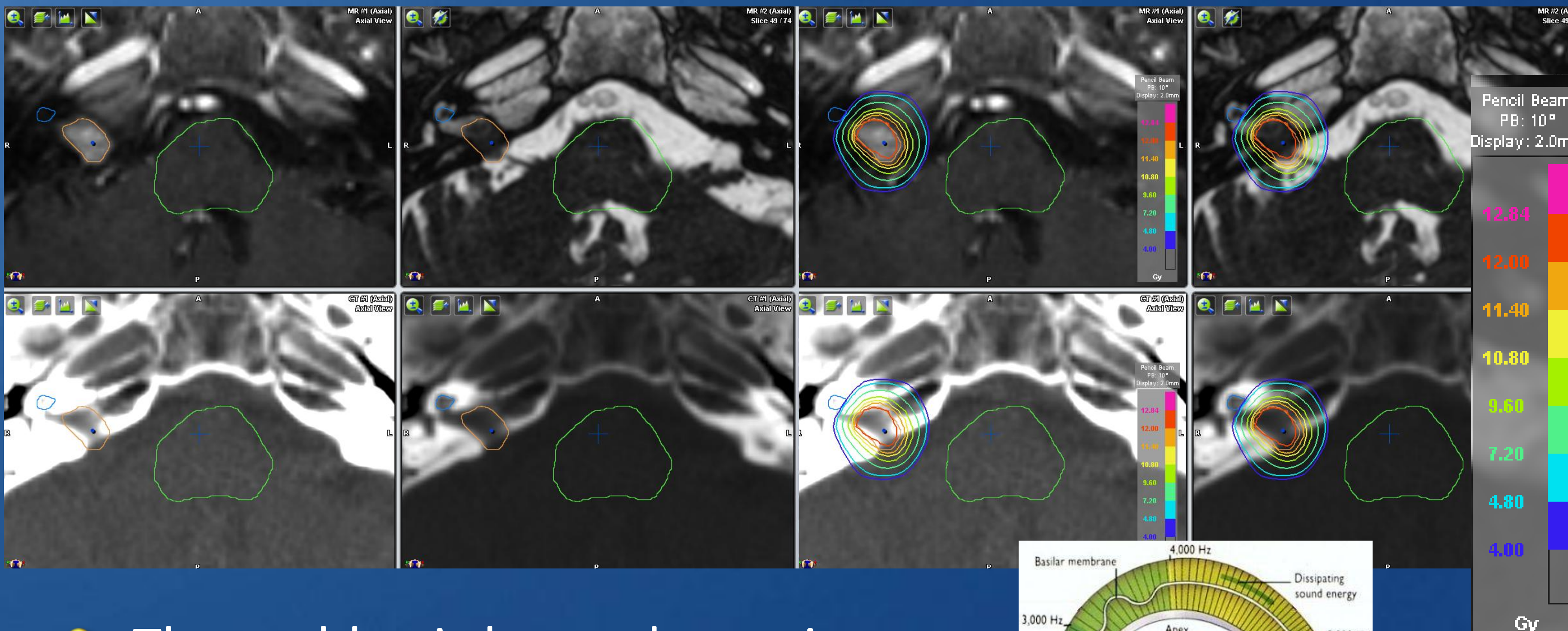
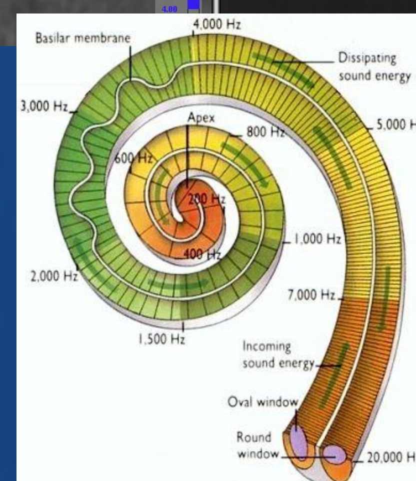
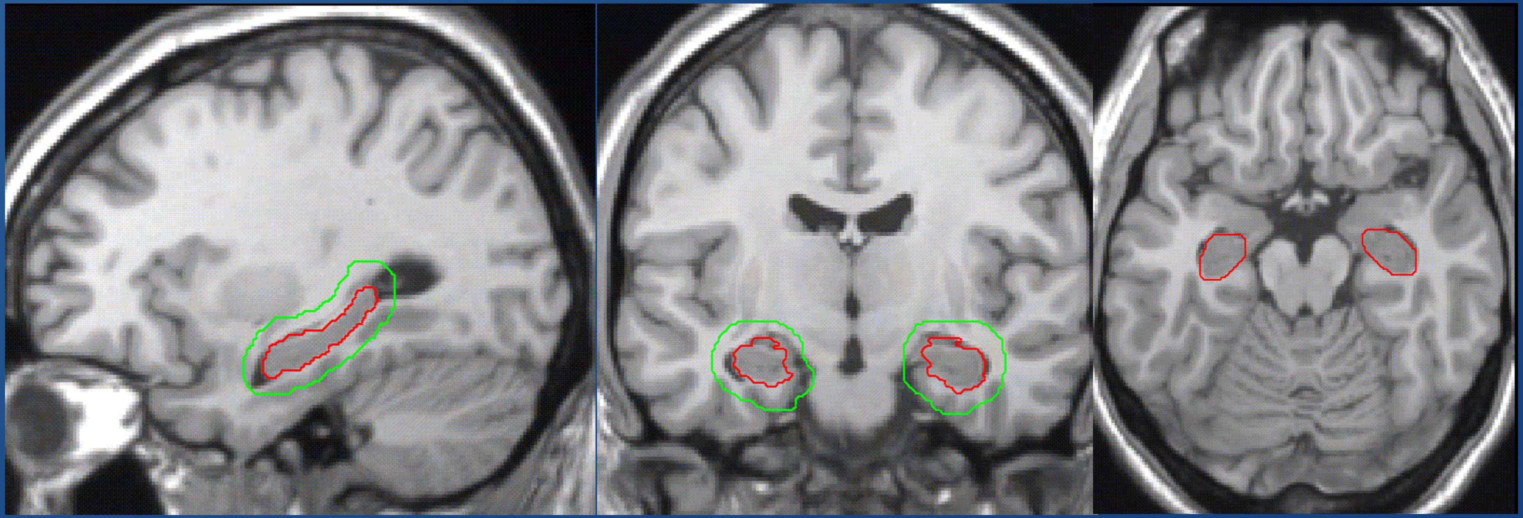



- The cochlea is located anterior to the internal auditory canal
- Auditory perception is tonotopic
- Different frequencies are heard in different locations



# Hippocampi

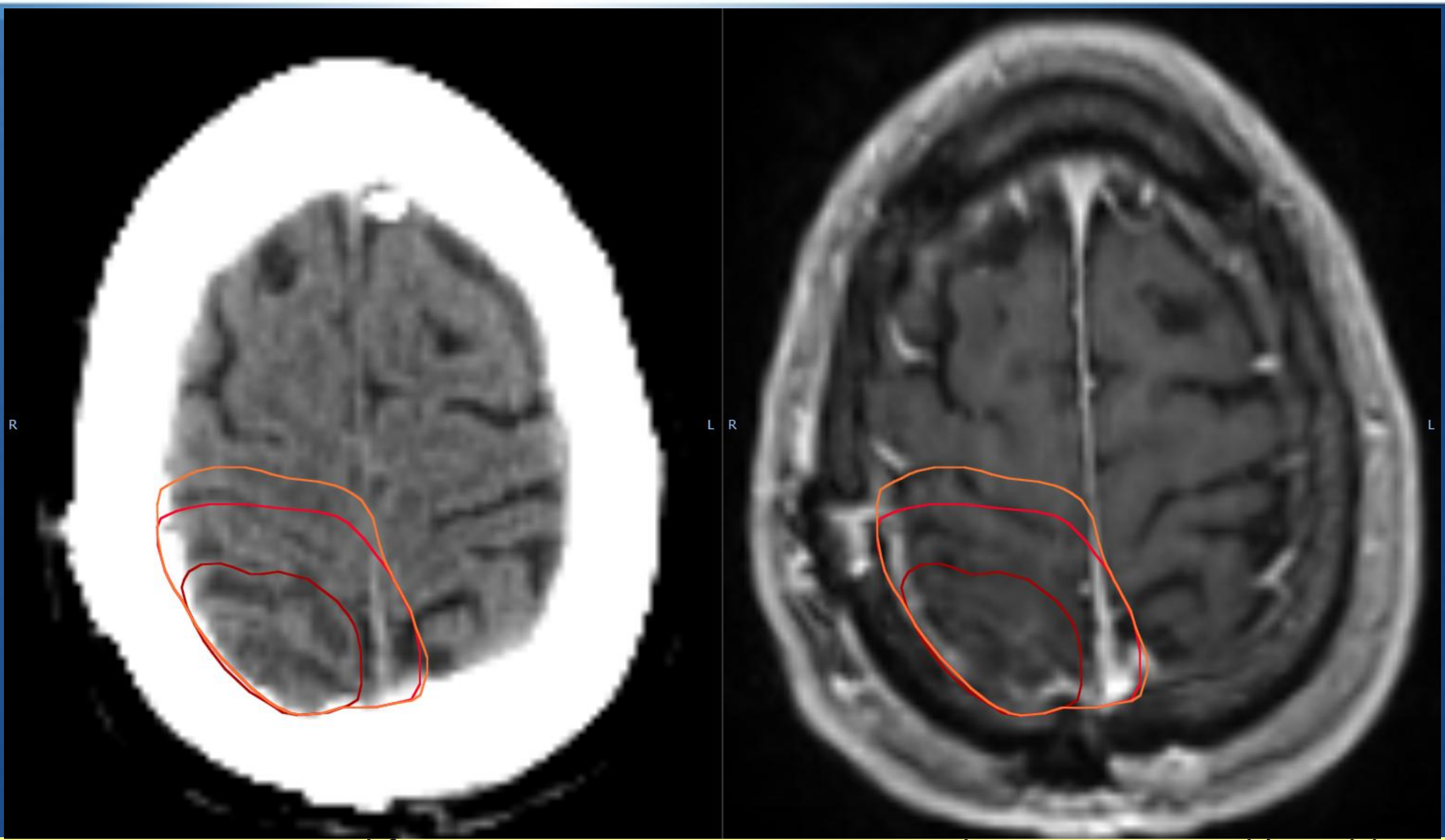
- Important because of potential adverse impact on short-term memory formation from radiotherapy
- Subependymal stem cells in the subgranular zone are felt to be important in generating short-term memory
- RTOG 0933 tests WBRT with hippocampal avoidance



BS Chera et al. Am J Clin Oncol. 32(1):20-2, 2009.

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

# Atypical Meningioma

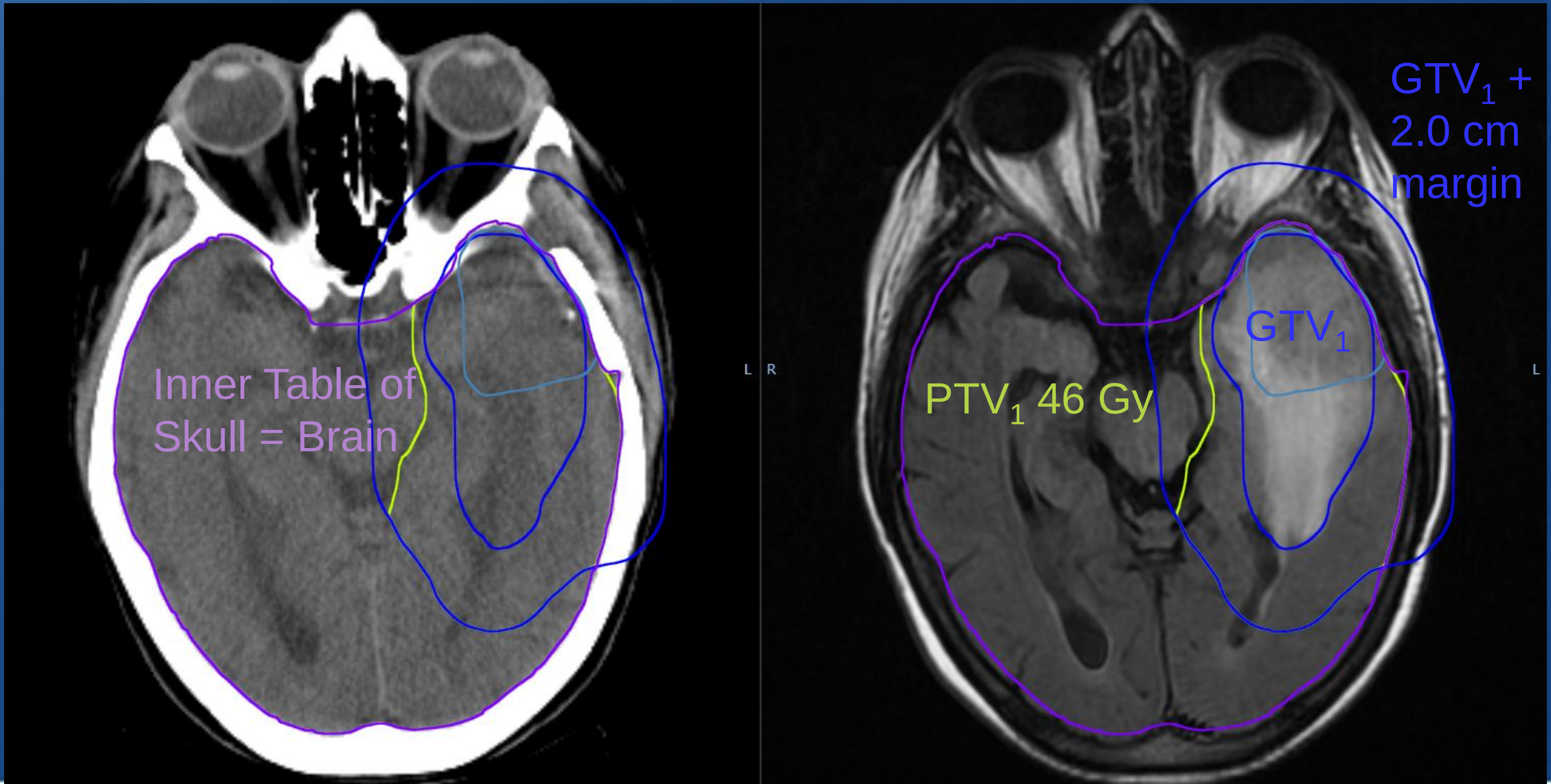



- GTV was generated from preoperative MRI.  PTV1 and PTV2 generated by adding 2 cm margin and 1.5 cm margins and editing to to cover interhemispheric meninges without treating contralatereal cerebral cortex

# Glioblastoma Multiforme

North Shore-LIJ CANCER INSTITUTE

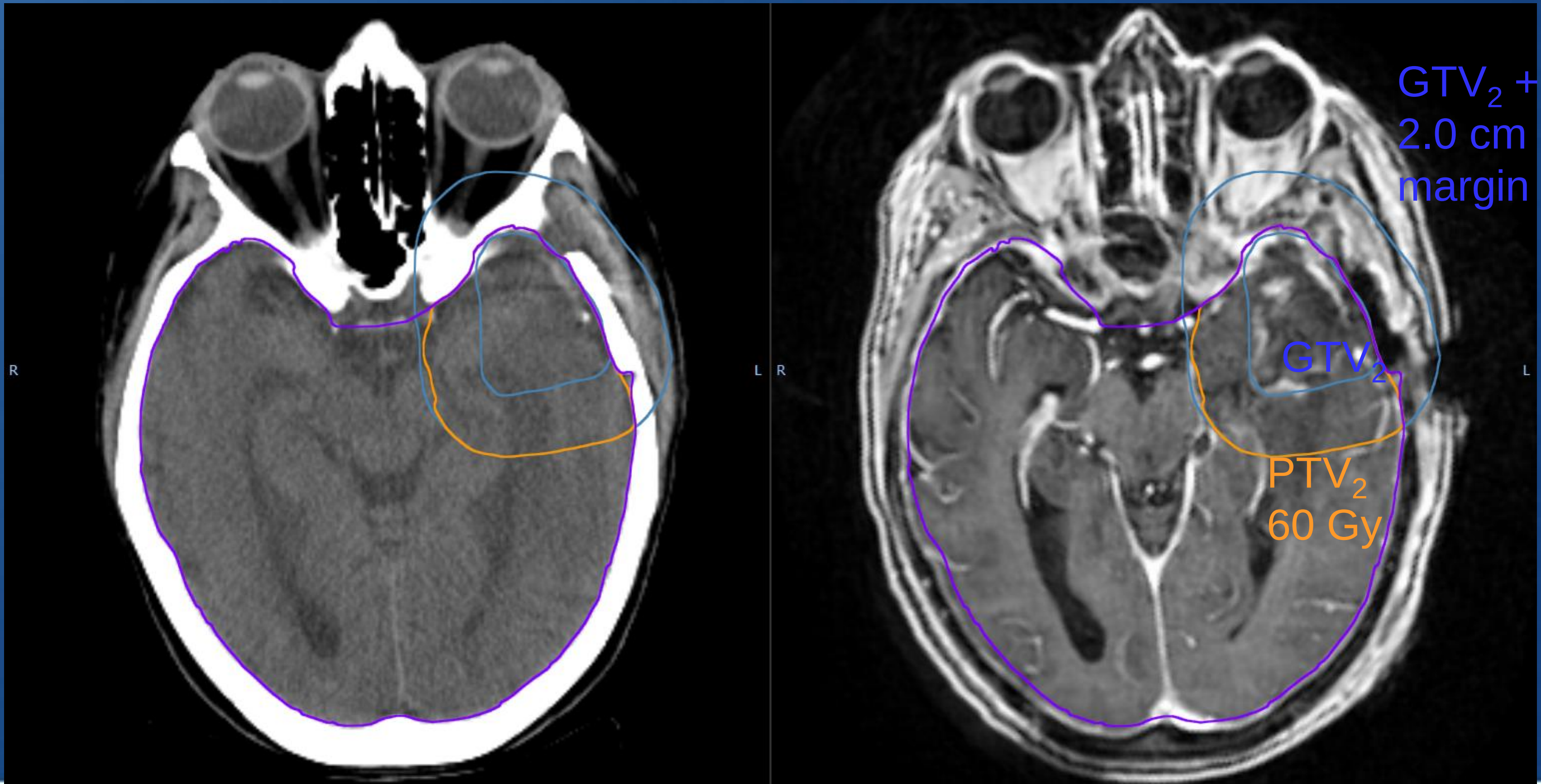
- $PTV_1$ (46 Gy) generated from contoured FLAIR and brain volumes, Boolean editing, and respecting anatomic barriers to tumor spread



# Glioblastoma Multiforme

North Shore-LIJ CANCER INSTITUTE

- $PTV_2$ (60 Gy) generated from postoperative volumetric contrast-enhanced MRI, Boolean processes (including $PTV_1$)



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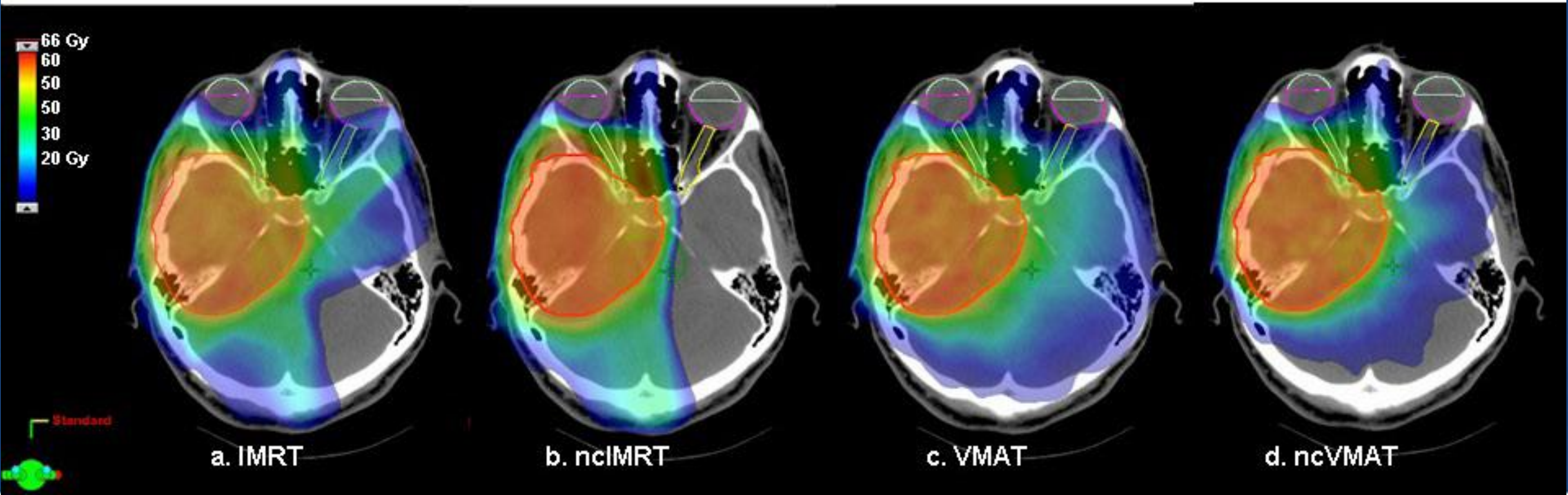
- Inaccurate GTV contouring and less-than-logical CTV and PTV generation will increase volumes getting high-dose radiation and may make treatment planning more difficult
- Gliomas will not cross a dural surface (e.g. into the cerebellum from the cerebrum) or a CSF containing space—they spread along white matter pathways



# Questions?

# Thank you

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