Sidney Kimmel Cancer Center
Jefferson Health | NCI – designated

Until every cancer is cured

Integrated Feathering for Craniospinal Irradiation

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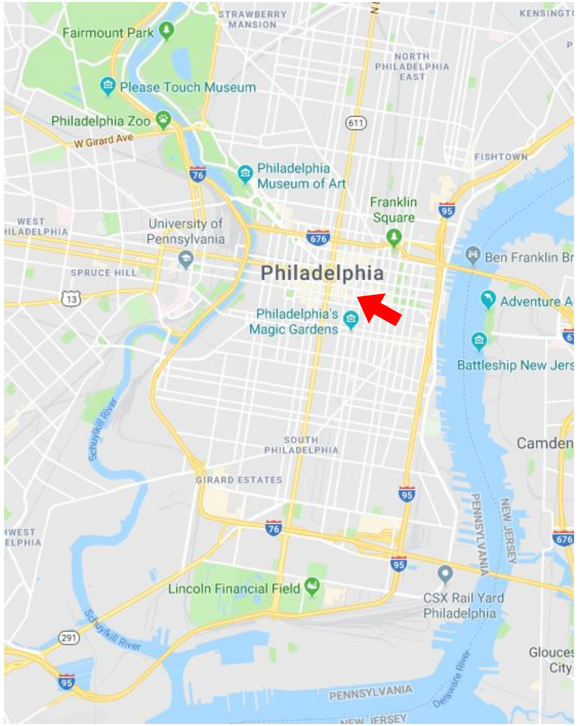
Jefferson University Hospital

TJU Radiation Oncology

- Center City, Philadelphia
- Bodine Center for Radiation Therapy
- 9 physicians
- 10 physicists
- 5 dosimetrists
- 23 therapists



TJU Radiation Oncology

- 2 Varian TrueBeams
- 2 Elekta Agilities
- 1 ViewRay (coming soon)

- VMAT, IMRT, 3D, TBI, TSET, …
- CSI
  - ~4/year

Outline

Background

Classic CSI

Integrated Feathering

Other CSI methods

Outline

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Classic CSI

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Other CSI methods

Medulloblastoma

- Tumor of the central nervous system (CNS)
- Occurs in both children and adults
  - Most common malignant brain tumor in children
- Usually originate in the cerebellum
- Spreads to CNS through cerebrospinal fluid

https://www.cancer.gov/rare-brain-spine-tumor/tumors/medulloblastoma

Medulloblastoma

Symptoms

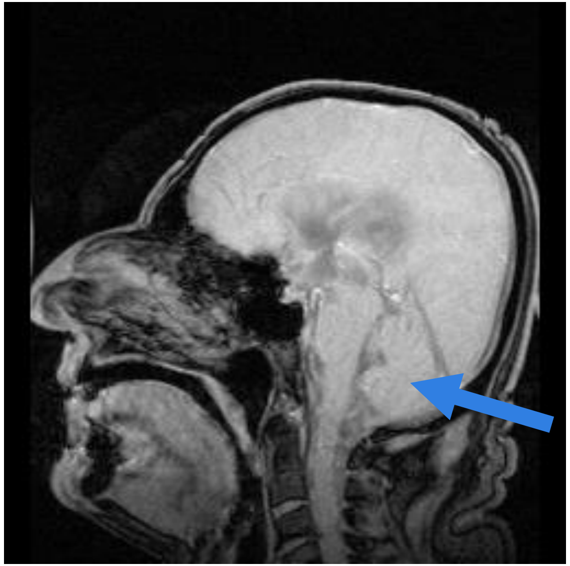
- Headaches
- Nausea or vomiting
- Clumsiness
- Problems with handwriting
- Visual problems

Symptoms (if spread to spine)

- Back pain
- Trouble walking
- Problems controlling bladder and bowel functions

https://www.stjude.org/disease/medulloblastoma.html

Cerebrospinal Fluid (CSF)



Cerebellum

Craniospinal Irradiation (CSI)

- Treat meduloblastoma and other tumors that may spread through CSF
- Irradiates the entire central nervous system
  - Whole brain and spine

History

CEREBELLAR MEDULLOBLASTOMA:
TREATMENT BY IRRADIATION OF THE WHOLE
CENTRAL NERVOUS SYSTEM

by

Edith Paterson and *R. F. Farr*

- First proposed in 1953 to irradiate “the entire brain and cord as one undivided volume”
- Principle from post-mortem findings of disease throughout the brain and cord

Outline

Background

Classic CSI

Integrated Feathering

Other CSI methods

Classic CSI

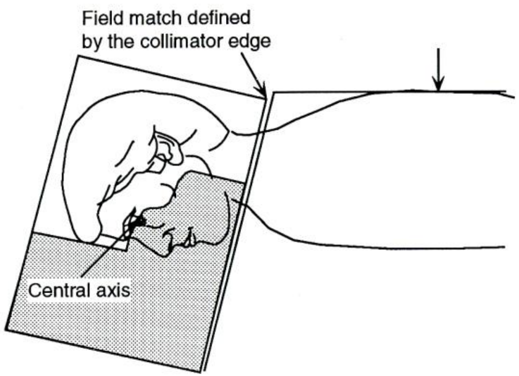
- Prone position
- Requires adjacent fields that must be matched
  - 2 opposed lateral whole brain fields
  - 1-2 posterior spinal fields
- Matching requires gantry, collimator, and couch rotations
- Important to avoid overdosing the spinal cord

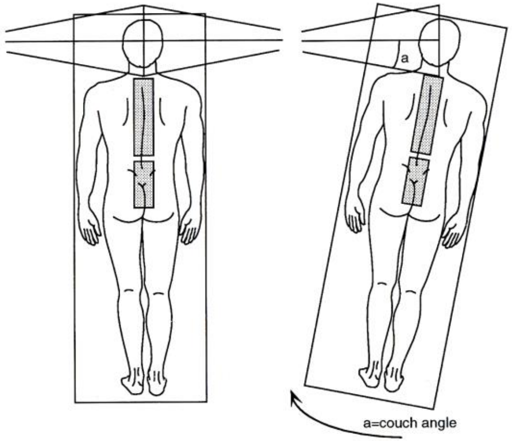
Spinal Fields

- Two spinal fields if spinal cord > 36 cm
- Children can usually be treated with one field
- Adults need two fields
  - “Matched” by employing a gap between fields

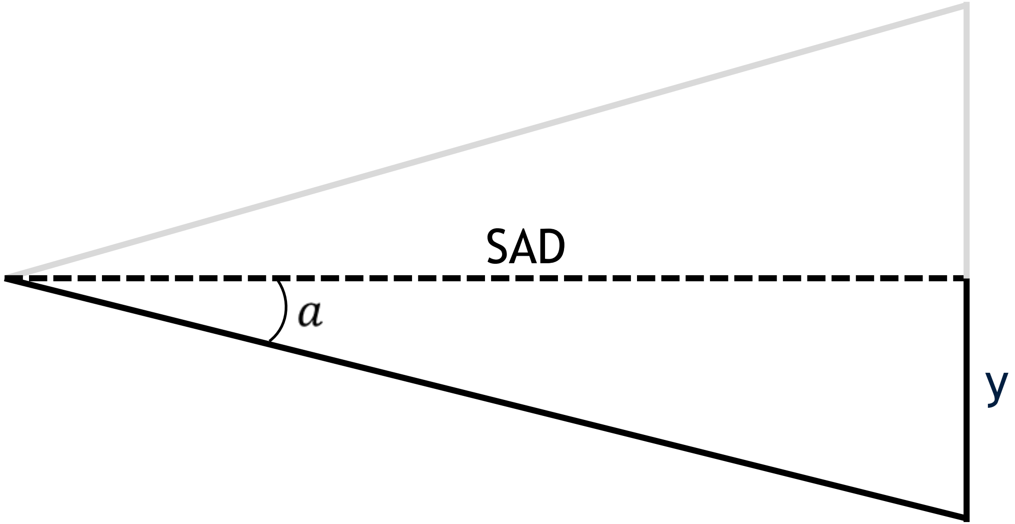
Field Matching

- Between lateral brain fields and superior spinal field
  - Requires collimator and couch rotation

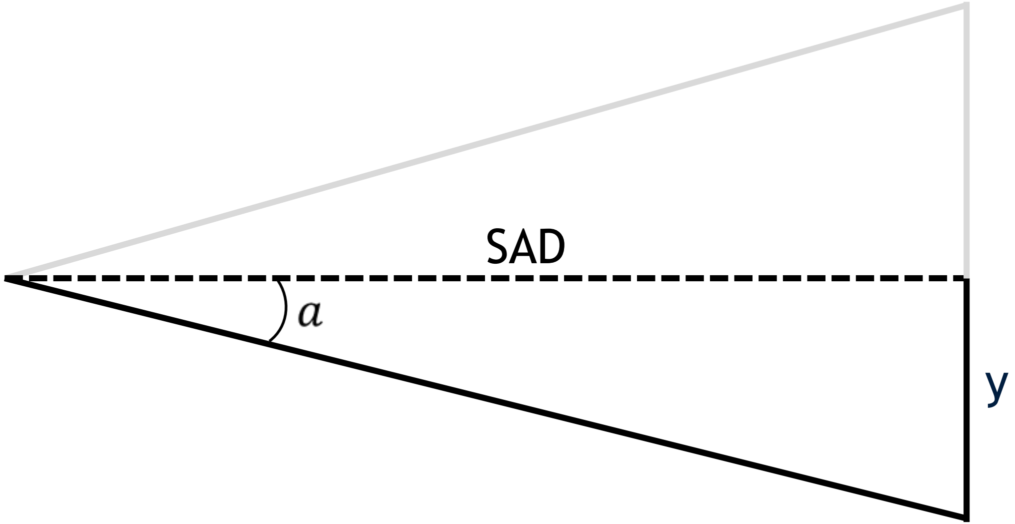




Couch Rotation

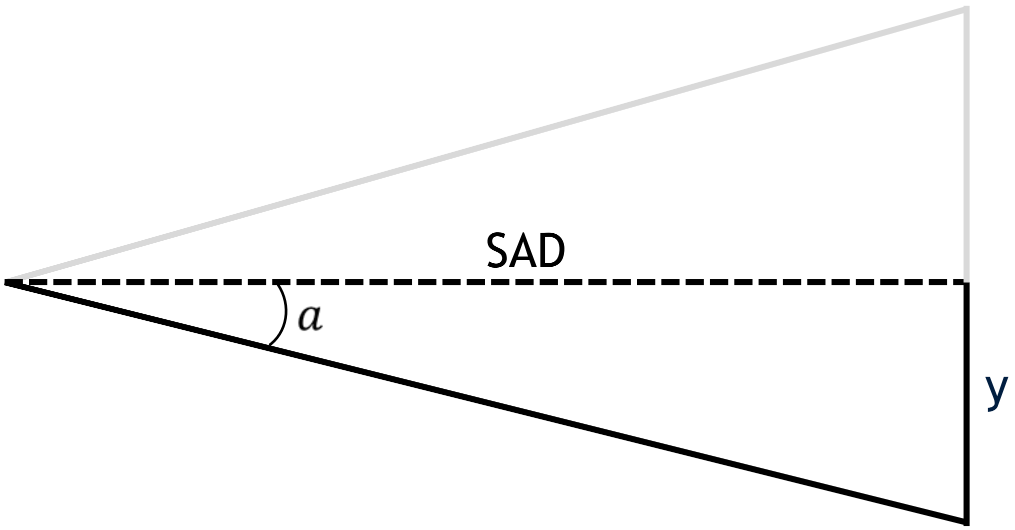


Couch Rotation



SOH
CAH
TOA

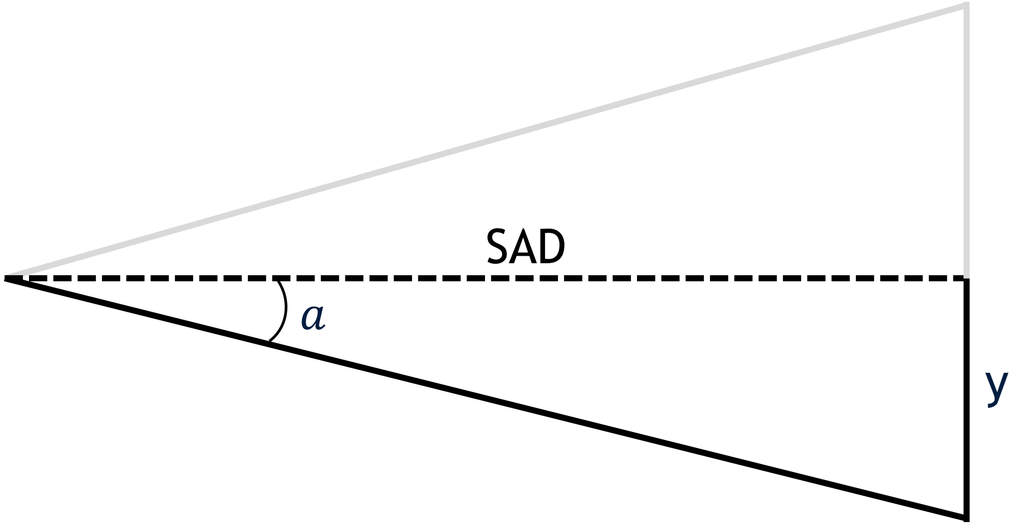
Couch Rotation



TOA

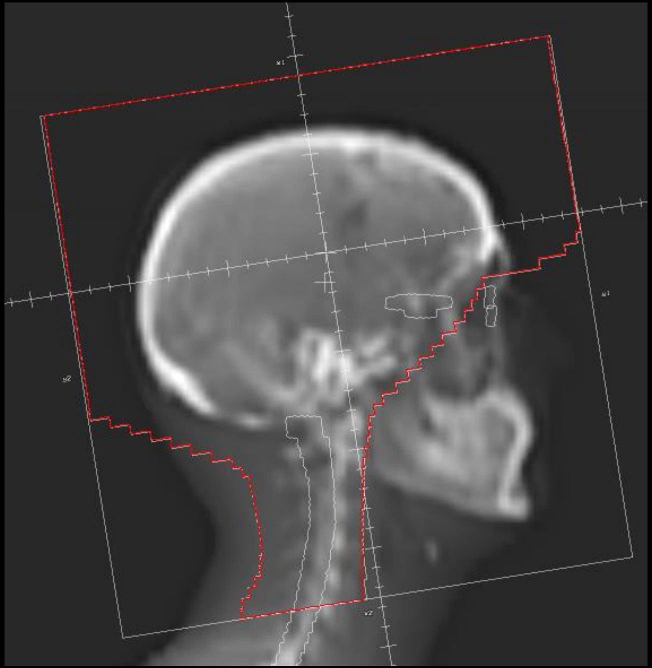
$$\tan x = \frac{opposite}{adjacent}$$

Couch Rotation



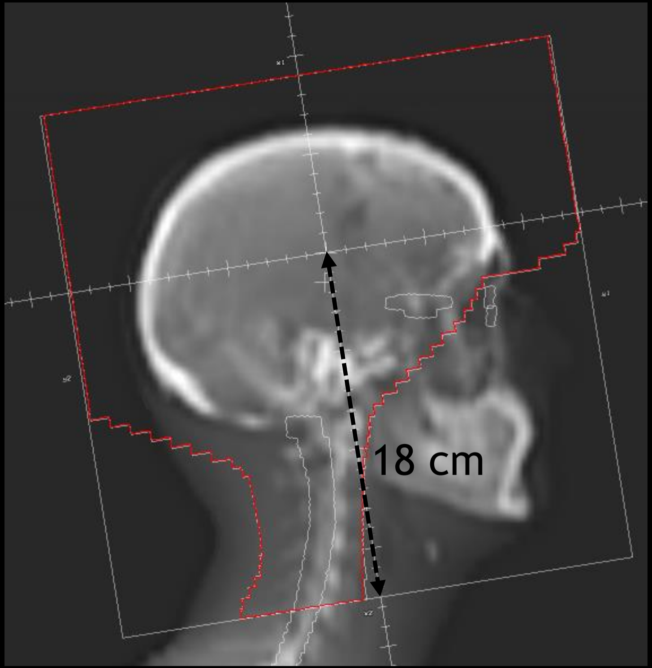
$$\tan a = \frac{y}{SAD}$$

Couch Rotation Example



$$\tan a = \frac{y}{SAD}$$

Couch Rotation Example



$$\tan a = \frac{y}{SAD}$$

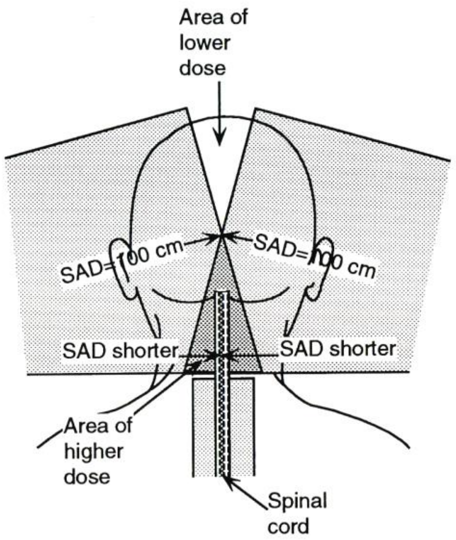
$$\tan a = \frac{18\ cm}{100\ cm}$$

$$a = \tan^{-1}\frac{18\ cm}{100\ cm}$$

$$a = 10.2°$$

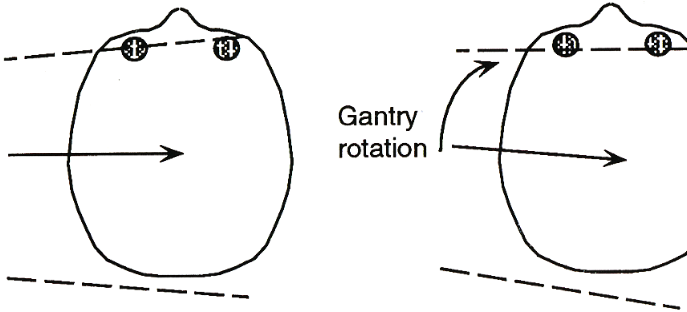
Field Matching

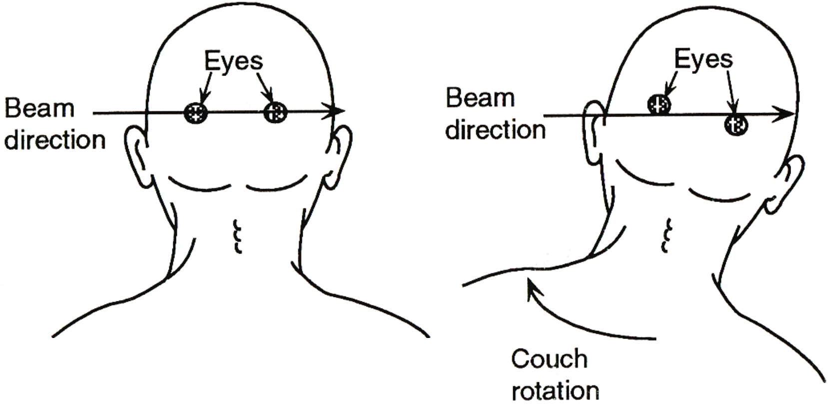
- Beware of overdosing the cervical spine



Field Arrangements

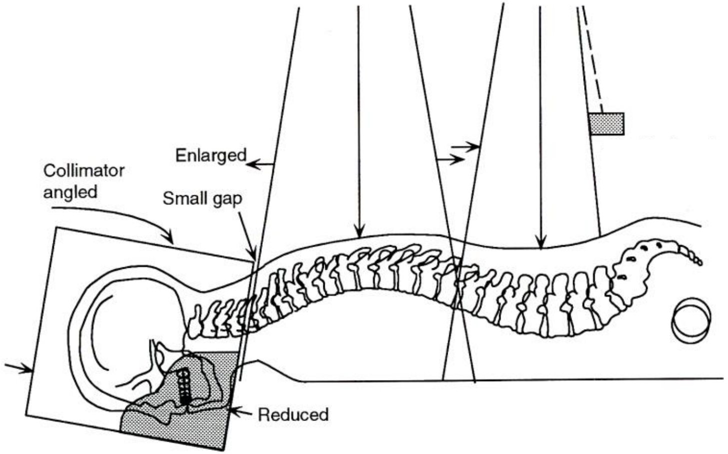
- Avoiding divergence into the eyes/lenses is difficult



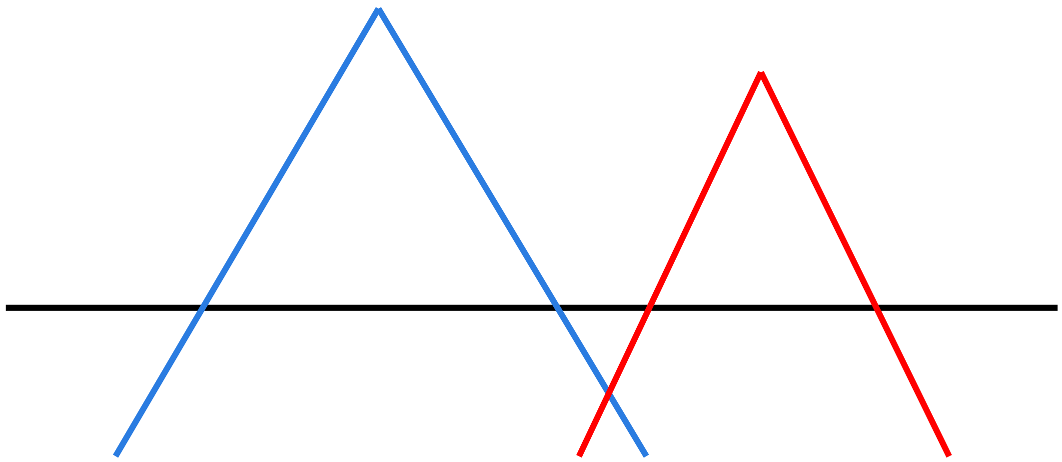


Field Matching

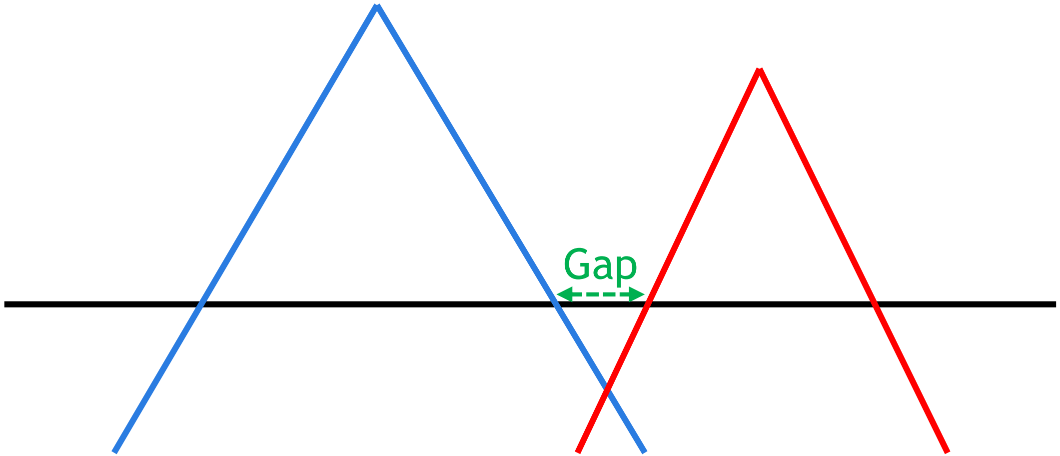
- Between two posterior spinal fields
- Gap calculation



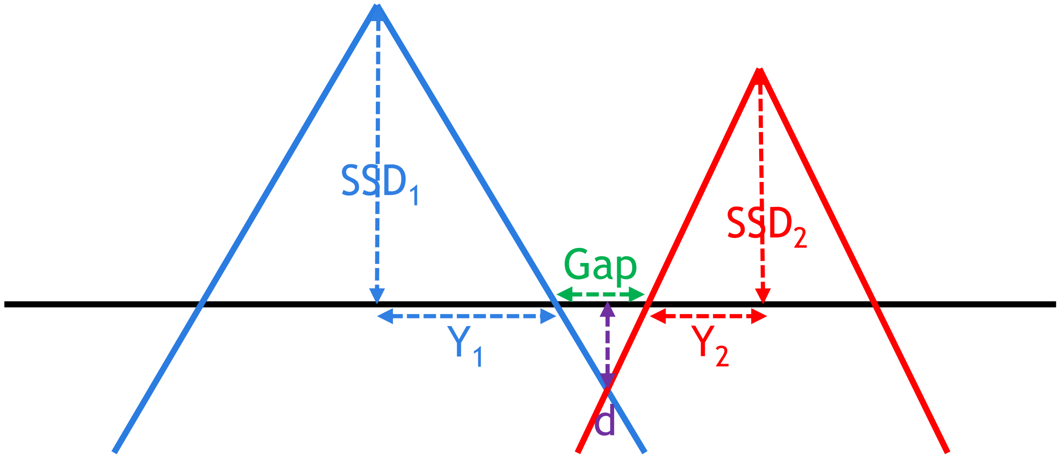
Gap Calculation



Gap Calculation

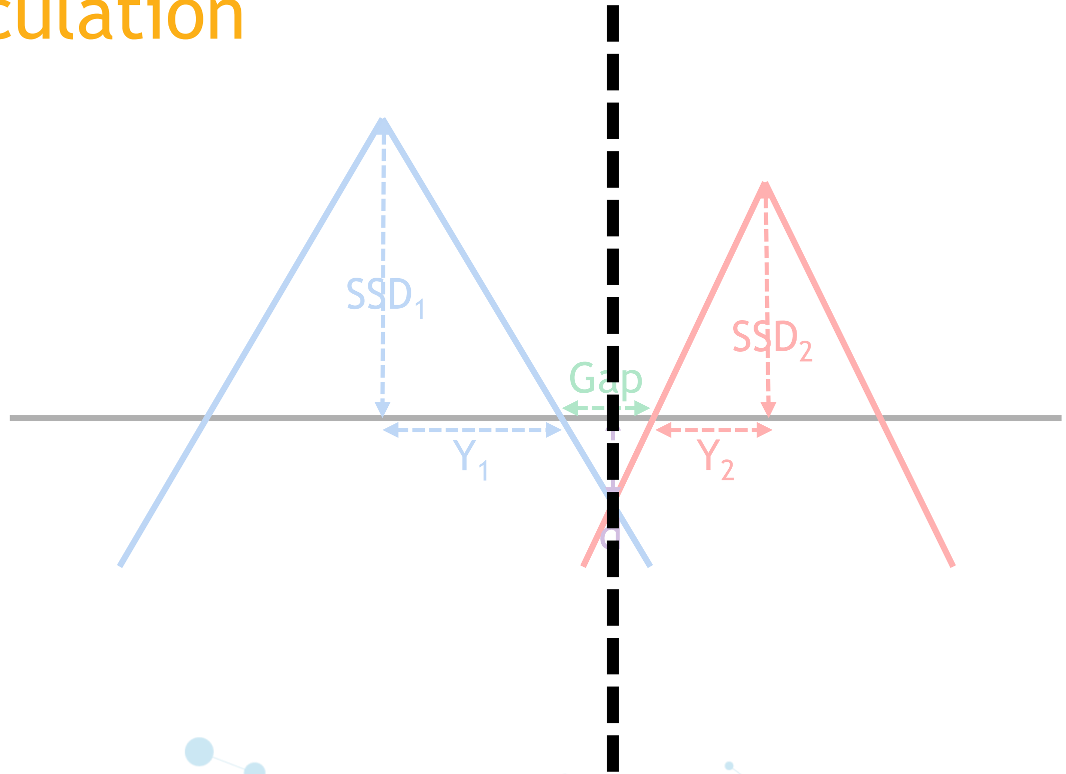


Gap Calculation

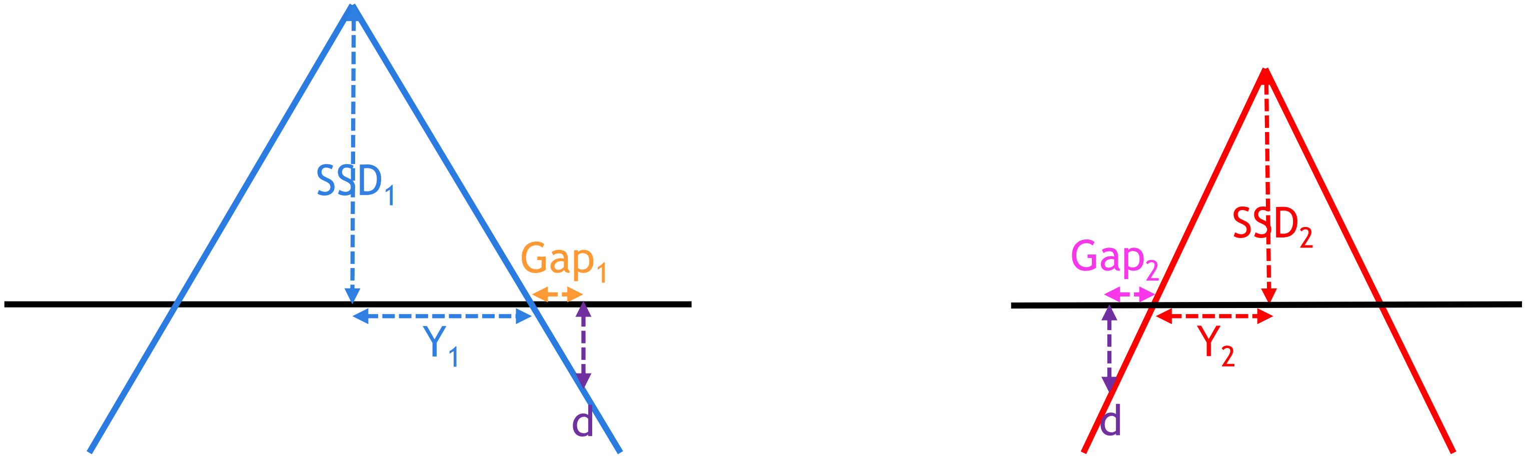


$$Gap = \frac{Y_1 d}{SSD_1} + \frac{Y_2 d}{SSD_2}$$

Gap Calculation

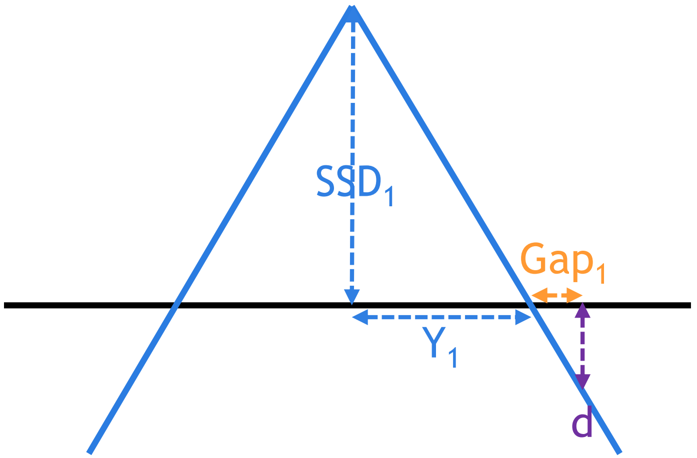


Gap Calculation

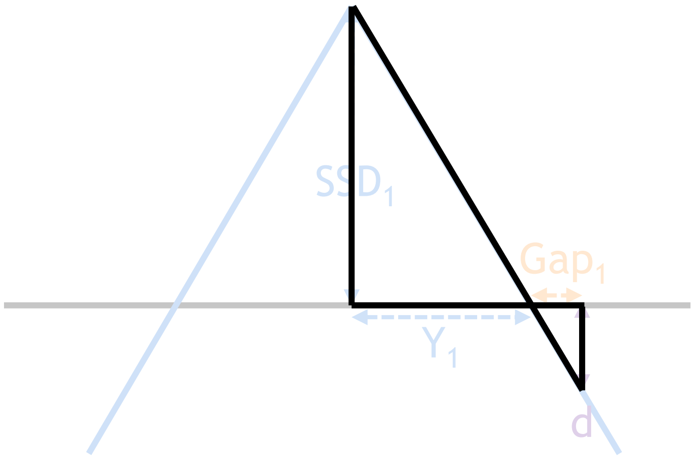


$$Gap = Gap_1 + Gap_2$$

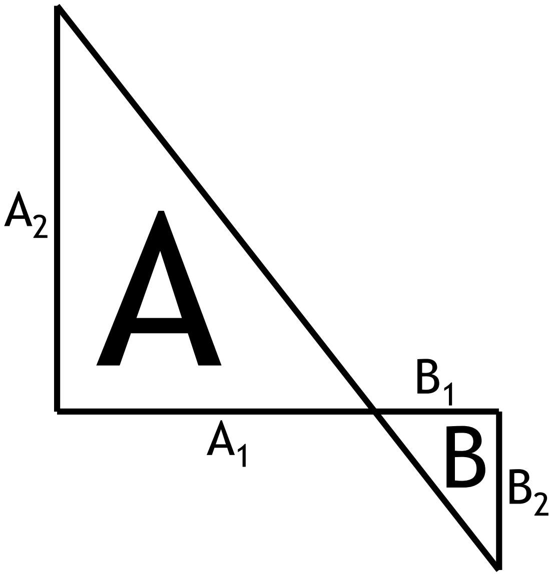
Gap Calculation



Gap Calculation

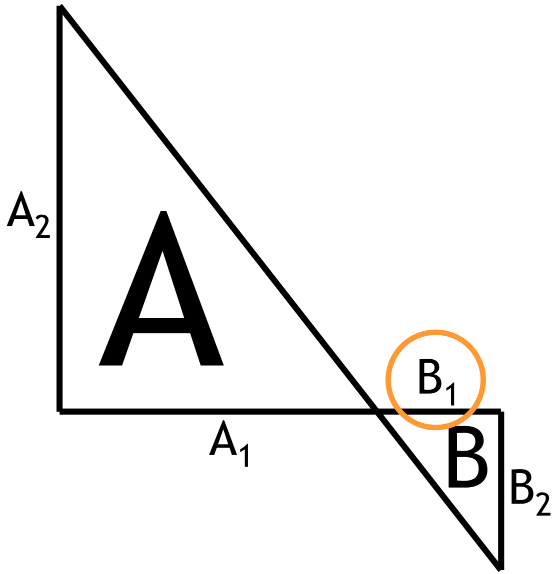


Gap Calculation



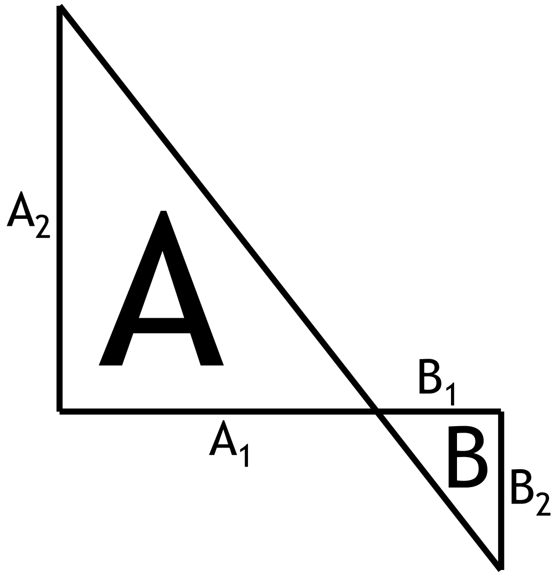
$$\frac{B_1}{B_2} = \frac{A_1}{A_2}$$

Gap Calculation



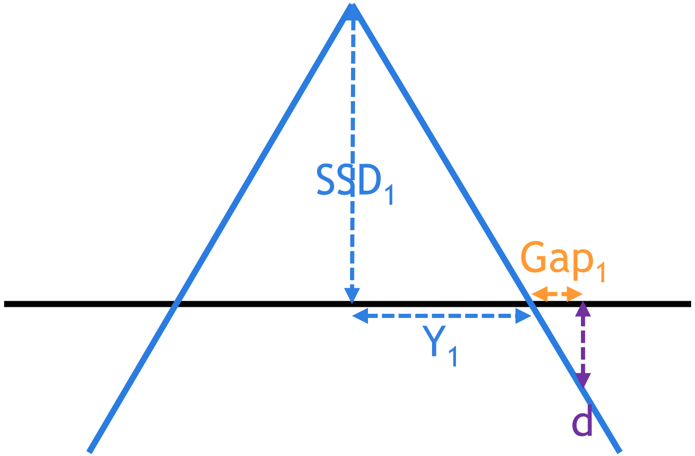
$$\frac{B_1}{B_2} = \frac{A_1}{A_2}$$

Gap Calculation



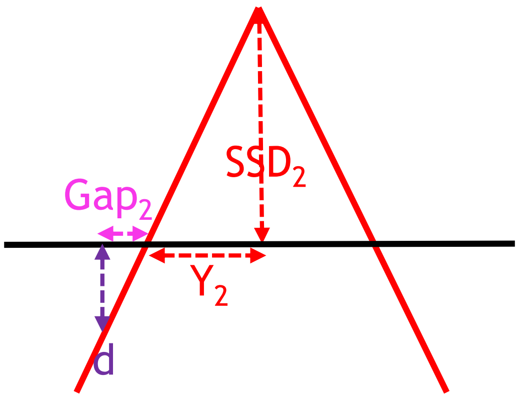
$$B_1 = \frac{A_1 B_2}{A_2}$$

Gap Calculation



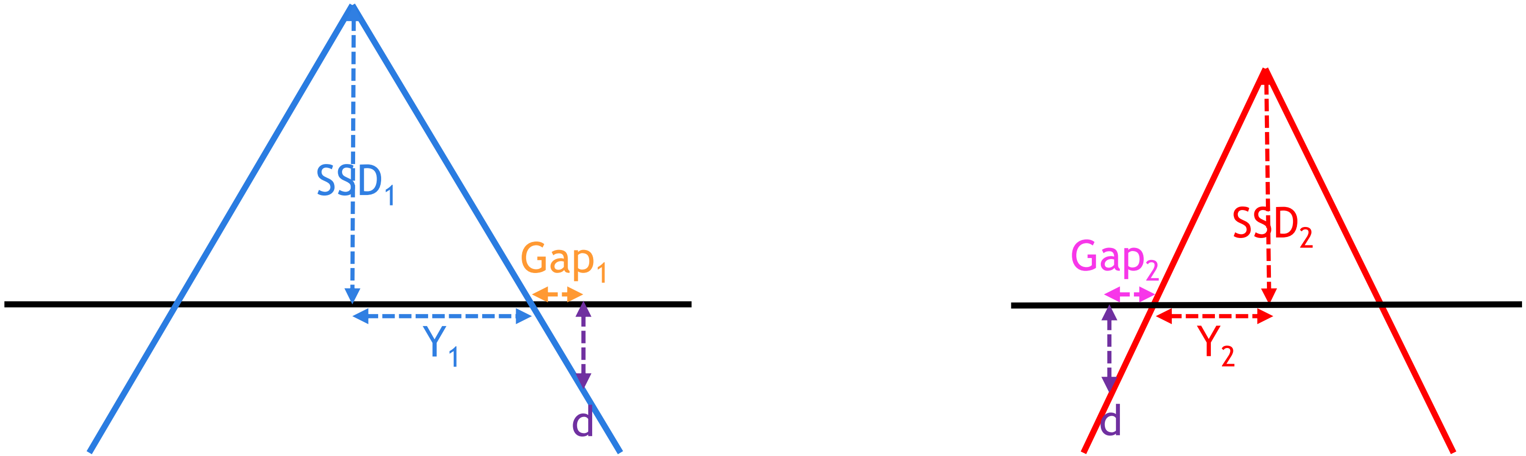
$$Gap_1 = \frac{Y_1 d}{SSD_1}$$

Gap Calculation



$$Gap_2 = \frac{Y_2 d}{SSD_2}$$

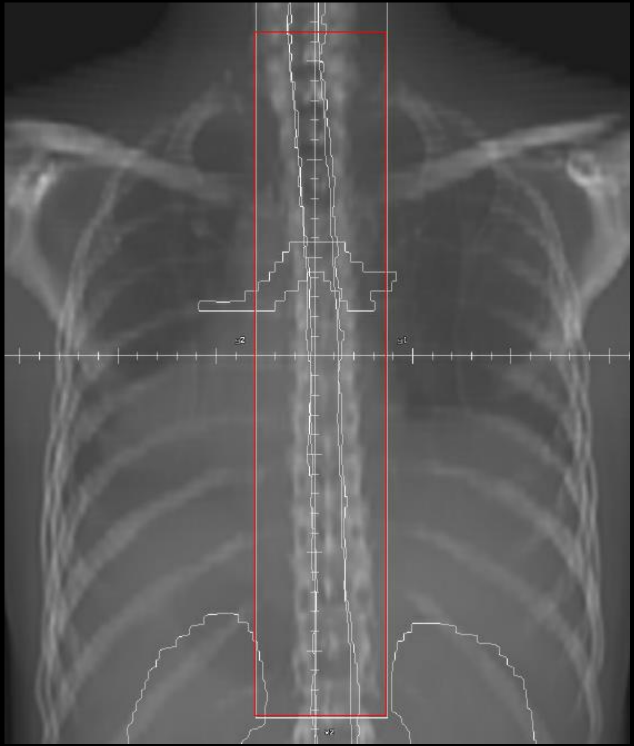
Gap Calculation



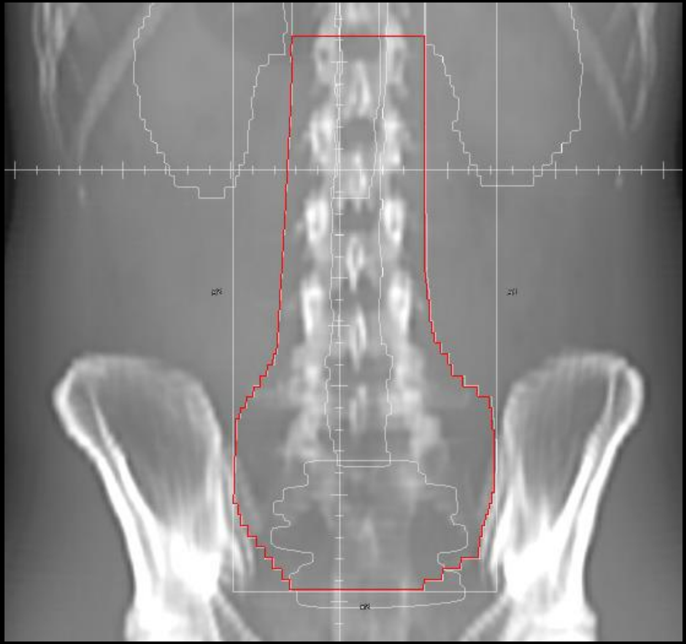
$$Gap = Gap_1 + Gap_2 = \frac{Y_1 d}{SSD_1} + \frac{Y_2 d}{SSD_2}$$

Gap Calculation Example

5 cm depth



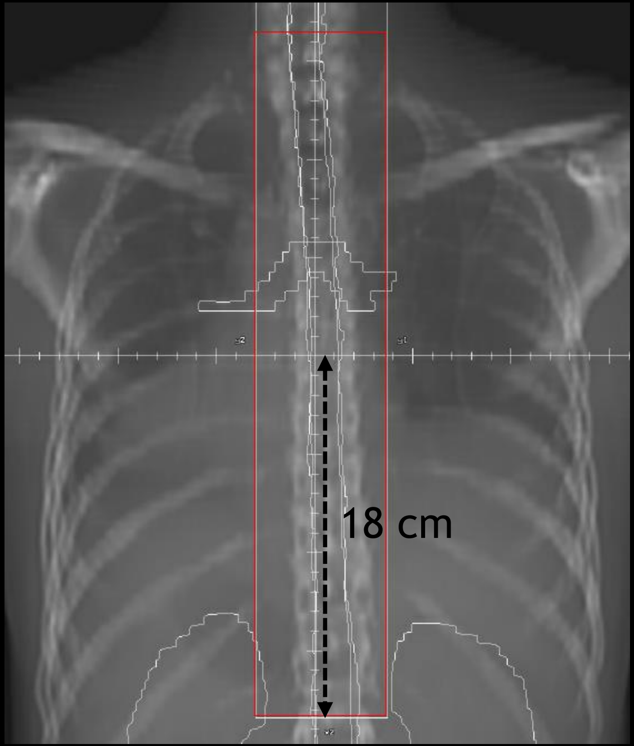
88 cm SSD



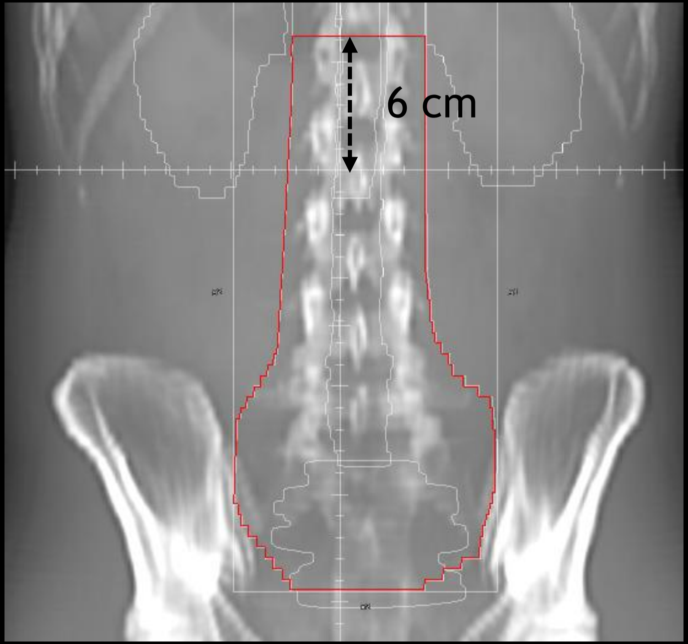
90 cm SSD

Gap Calculation Example

5 cm depth



88 cm SSD



90 cm SSD

Gap Calculation Example

$$Gap = \frac{Y_1 d}{SSD_1} + \frac{Y_2 d}{SSD_2}$$

$$d = 5\ cm$$
$$Y_1 = 18\ cm$$
$$SSD_1 = 88\ cm$$
$$Y_2 = 6\ cm$$
$$SSD_2 = 90\ cm$$

Gap Calculation Example

$$Gap = \frac{Y_1 d}{SSD_1} + \frac{Y_2 d}{SSD_2}$$

$$Gap = \frac{(18\ cm)(5\ cm)}{(88\ cm)} + \frac{(6\ cm)(5\ cm)}{(90\ cm)}$$

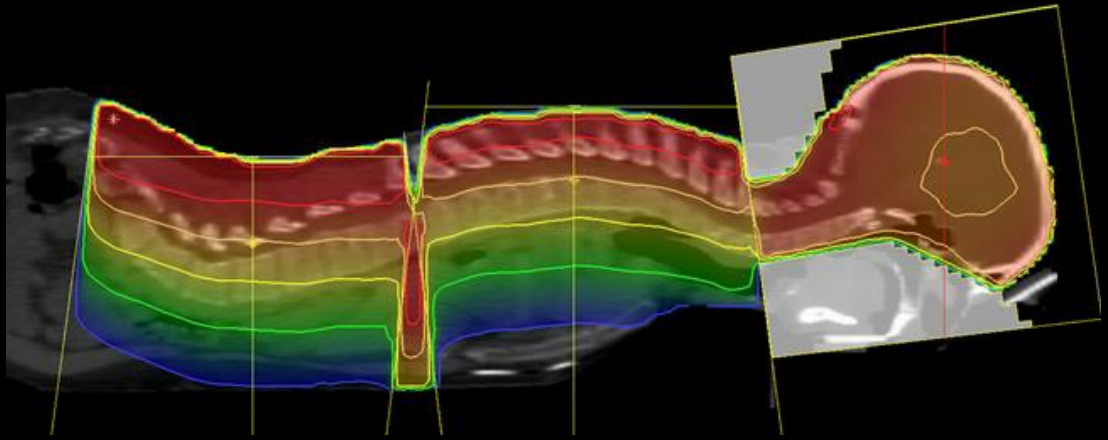
$$Gap = 1.02\ cm + 0.33\ cm$$

$$Gap = 1.35\ \text{cm}$$

$$d = 5\ cm$$
$$Y_1 = 18\ cm$$
$$SSD_1 = 88\ cm$$
$$Y_2 = 6\ cm$$
$$SSD_2 = 90\ cm$$

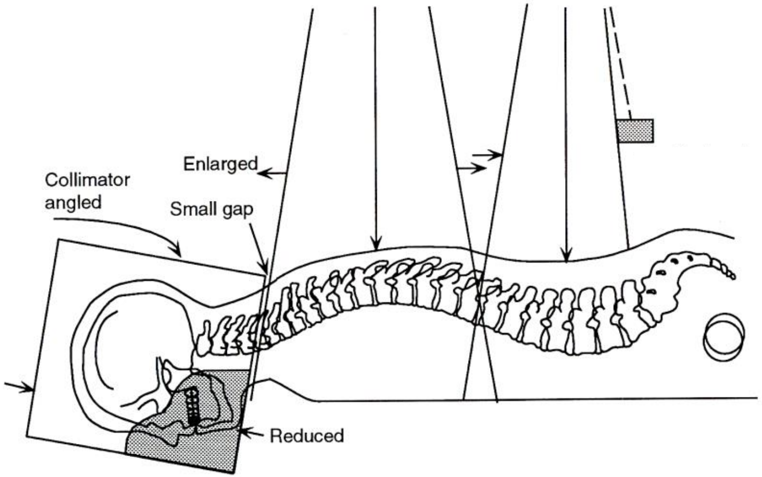
Field Borders

- Brain fields
  - Standard whole brain field with flash superiorly and posteriorly
- Upper spinal field
  - Junction with lower spinal field at around T12/L1
- Lower spinal field
  - Standard spade-shaped field

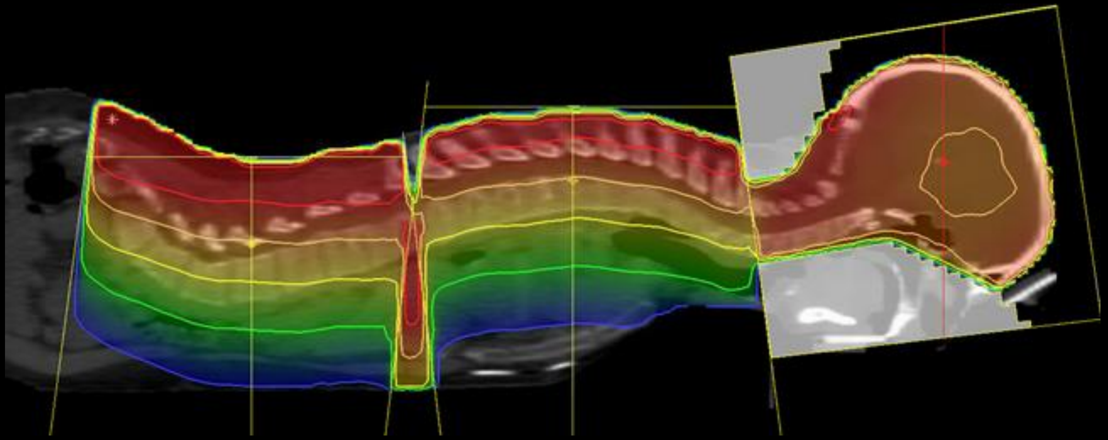


Feathering

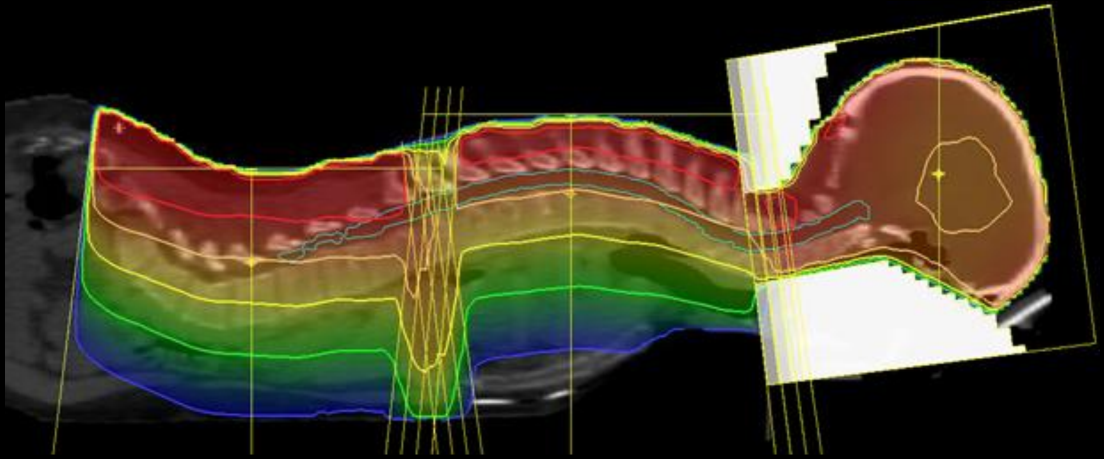
- Shift the field junction match lines throughout treatment
- Needs to be accounted for during planning
- Typically 1 cm shift
- Every 5-6 fractions



No feathering

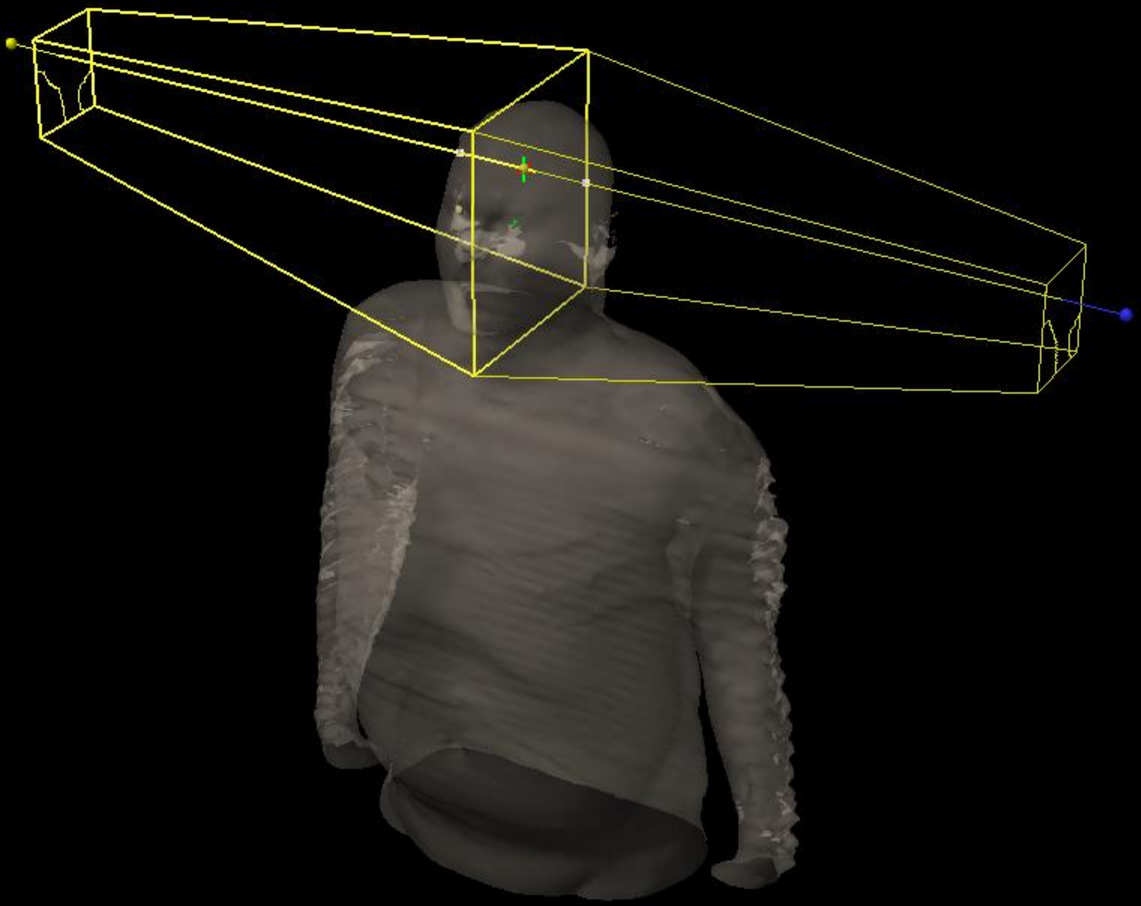


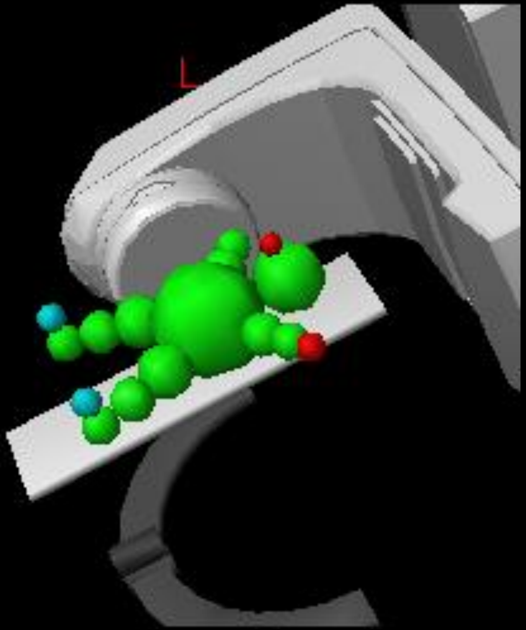
With feathering

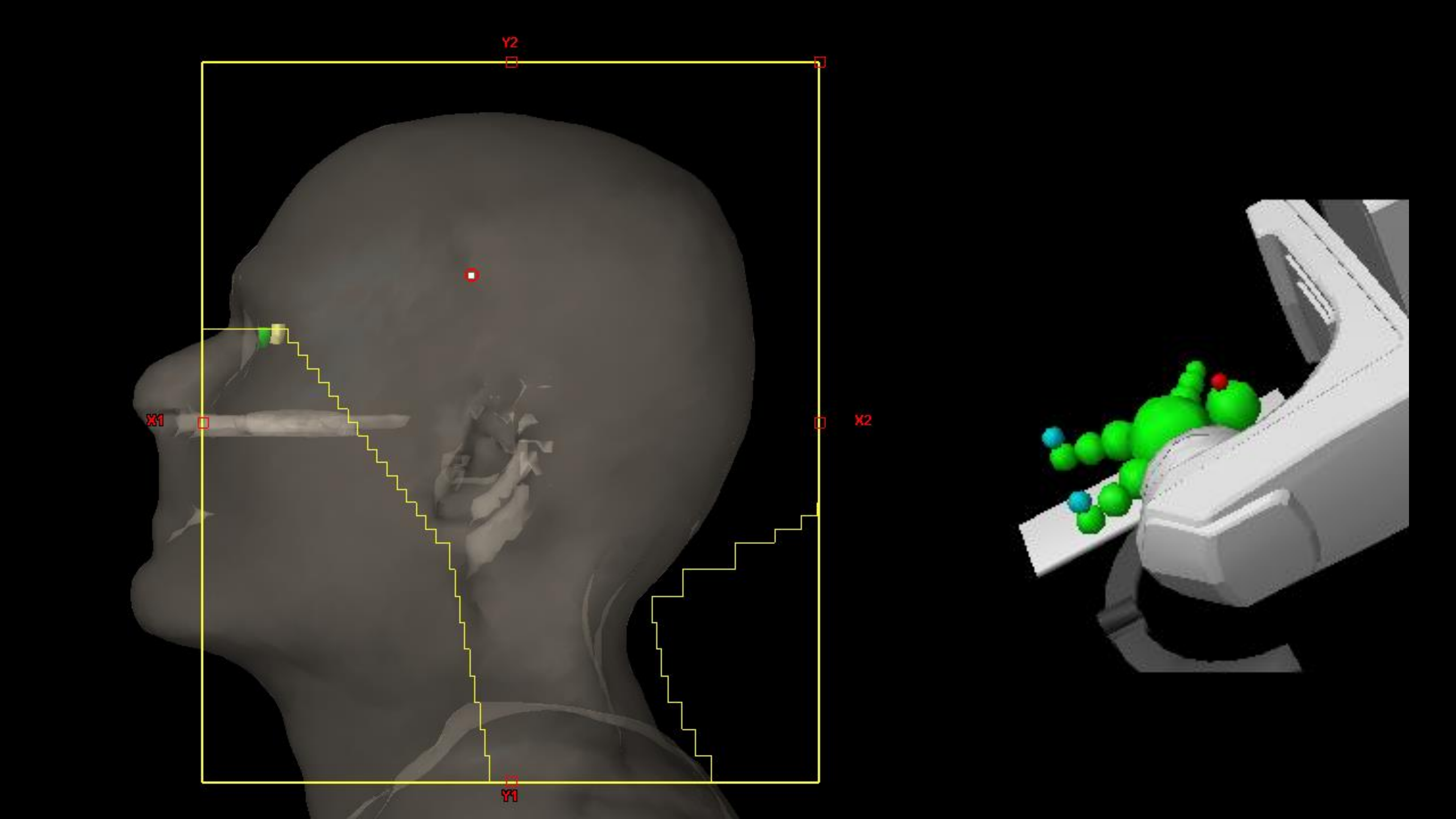


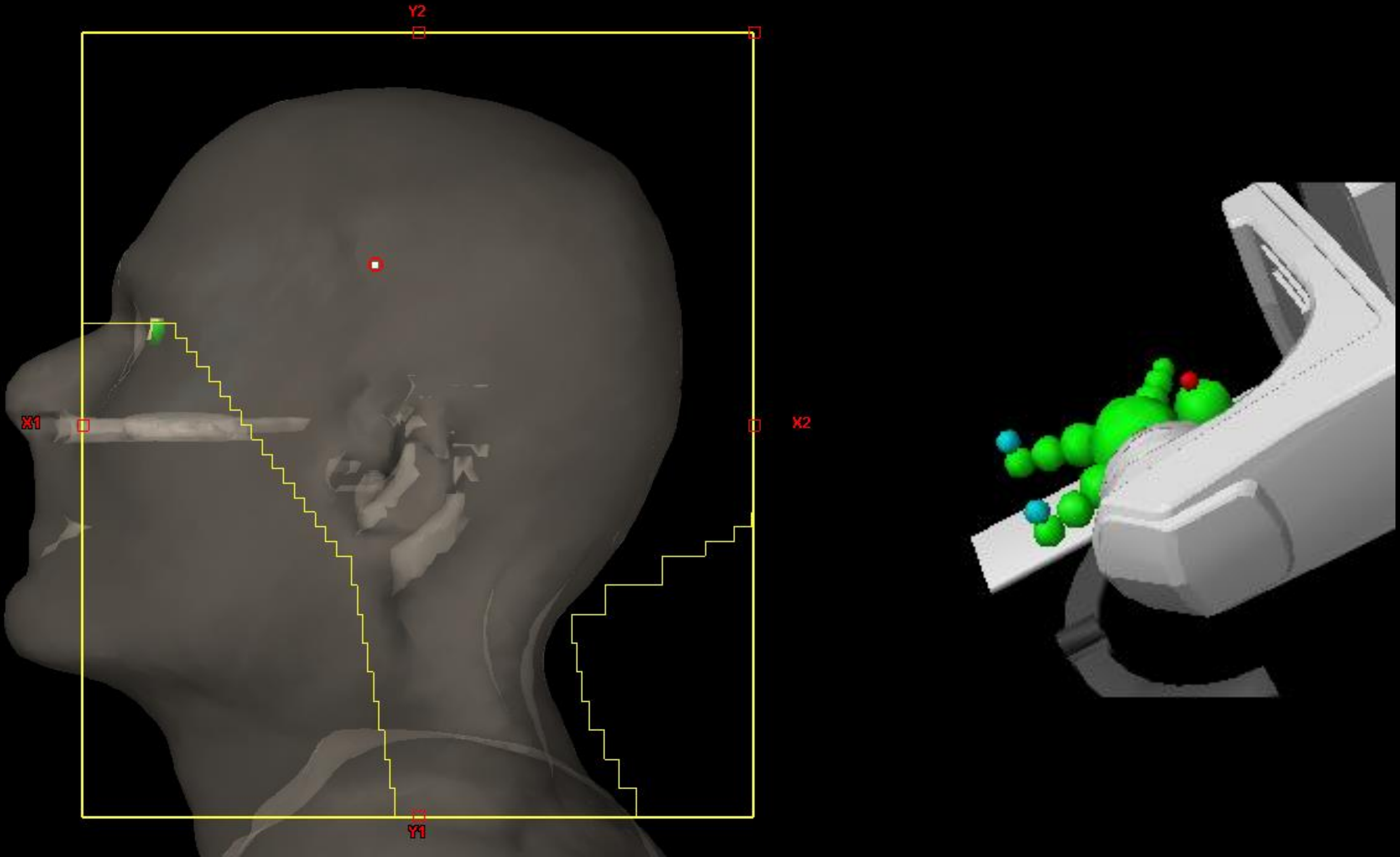
Patient Setup

- Prone
  - Visualize field junctions on patient surface with light fields
- Supine
  - More comfortable
  - More reproducible
- Head extended to allow for chin clearance for each feather

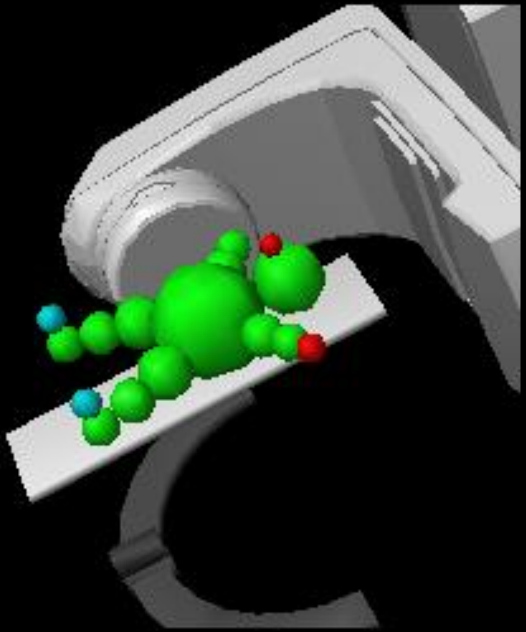


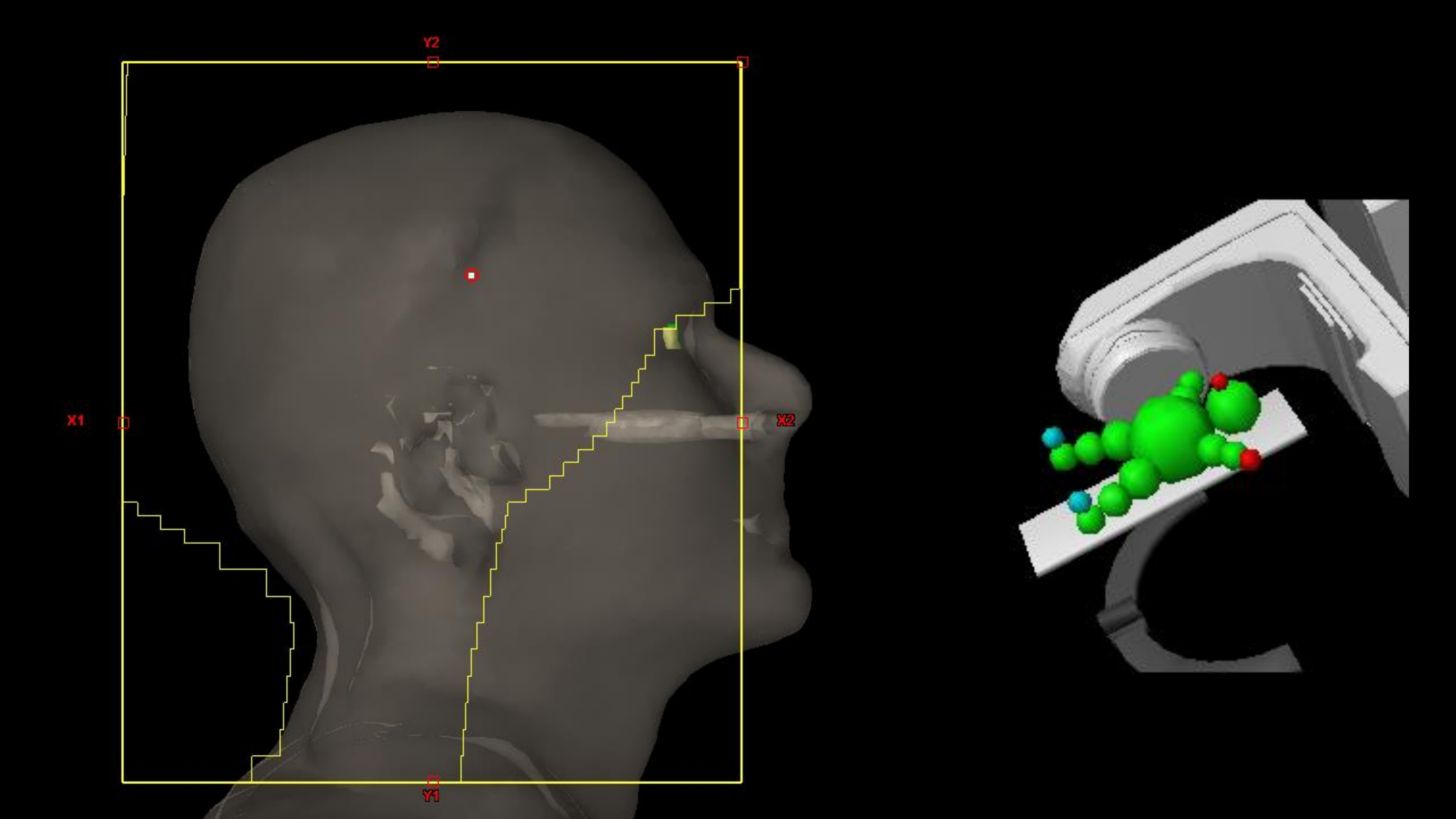

L

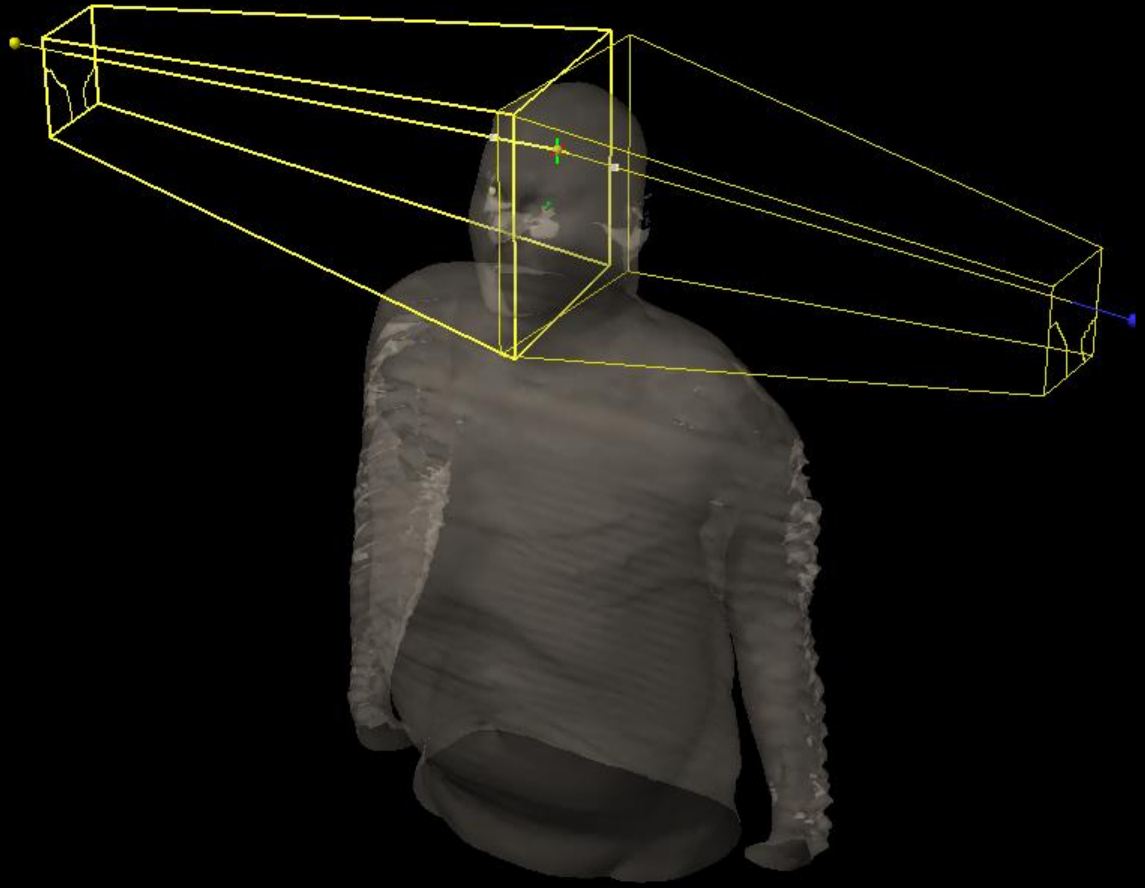

Y2
X1
X2
Y1

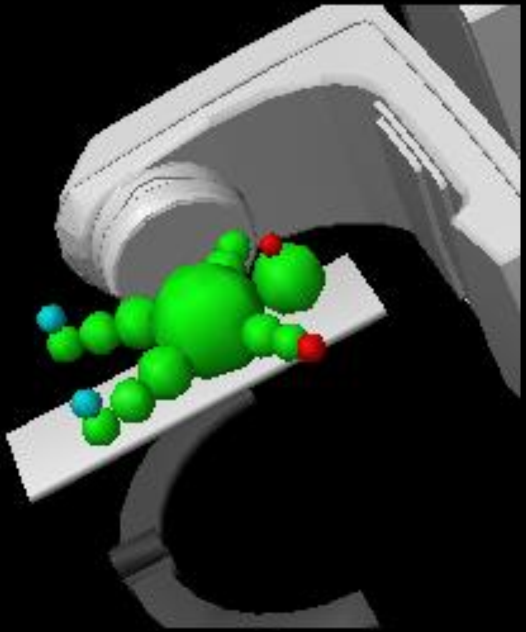

Y2
X1
X2
Y1

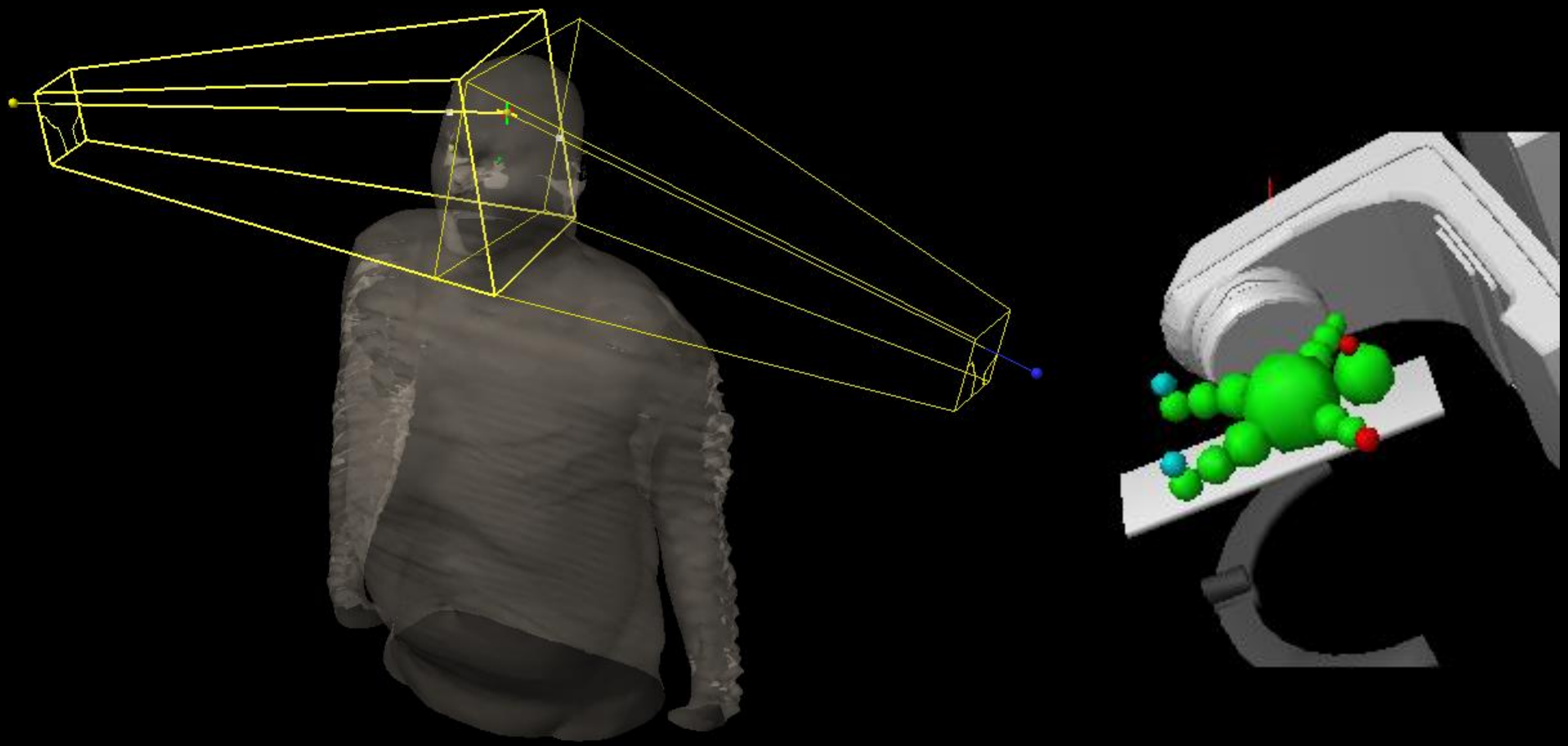

Y2
X1
X2
Y1

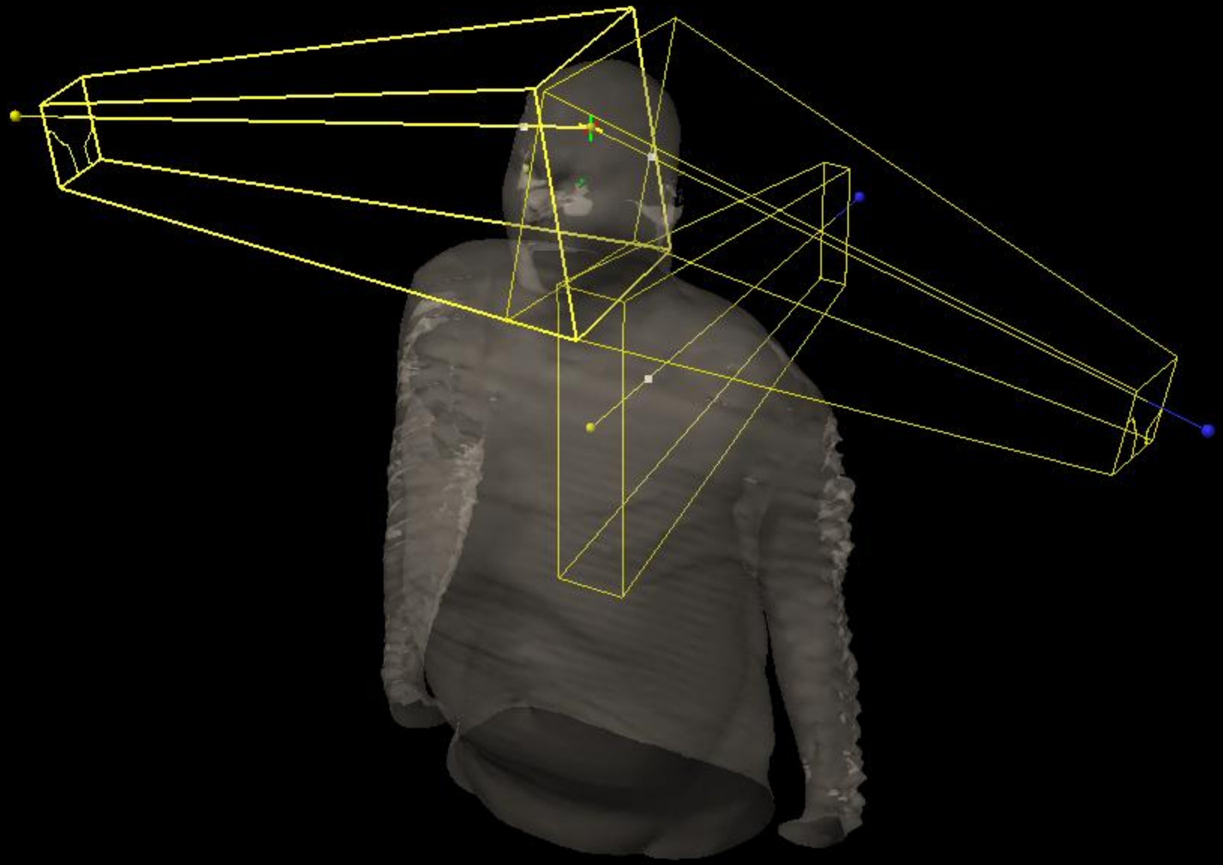


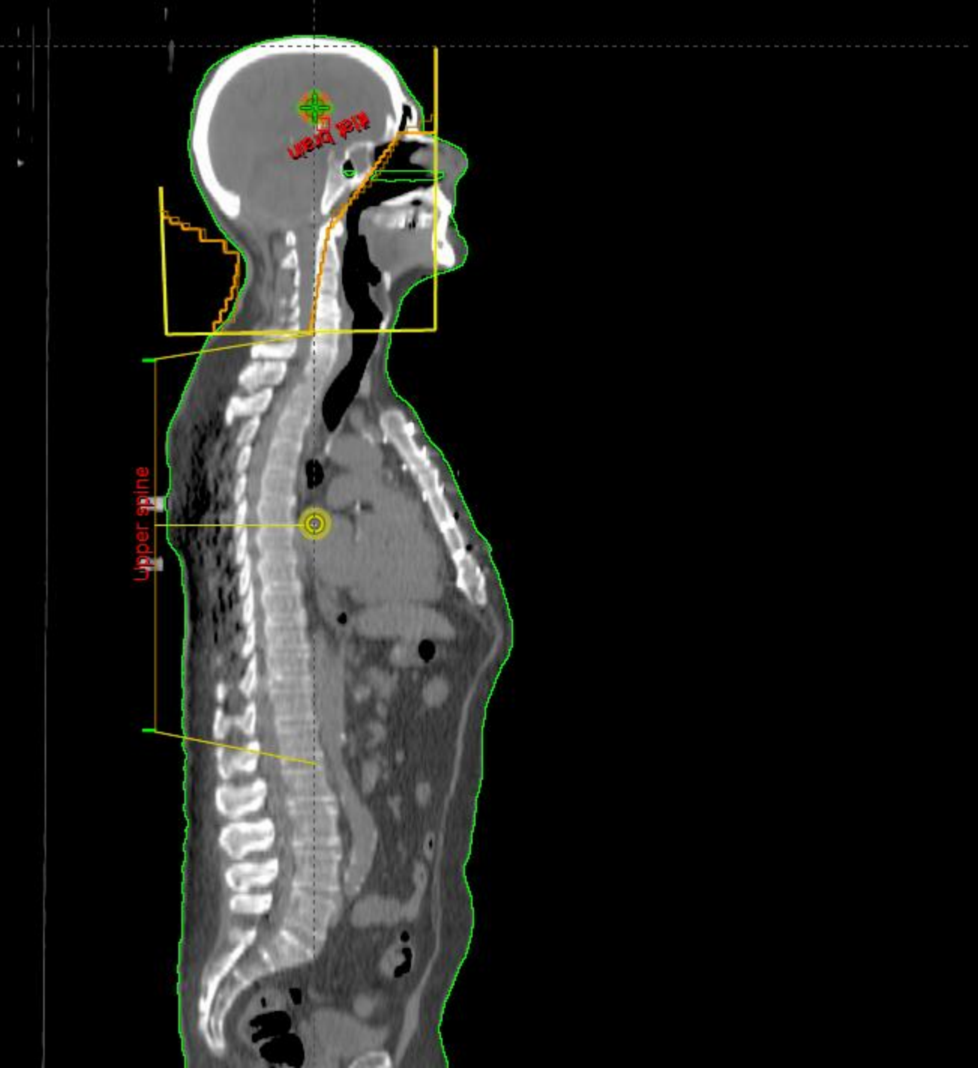

Y2
X1
X2
Y1

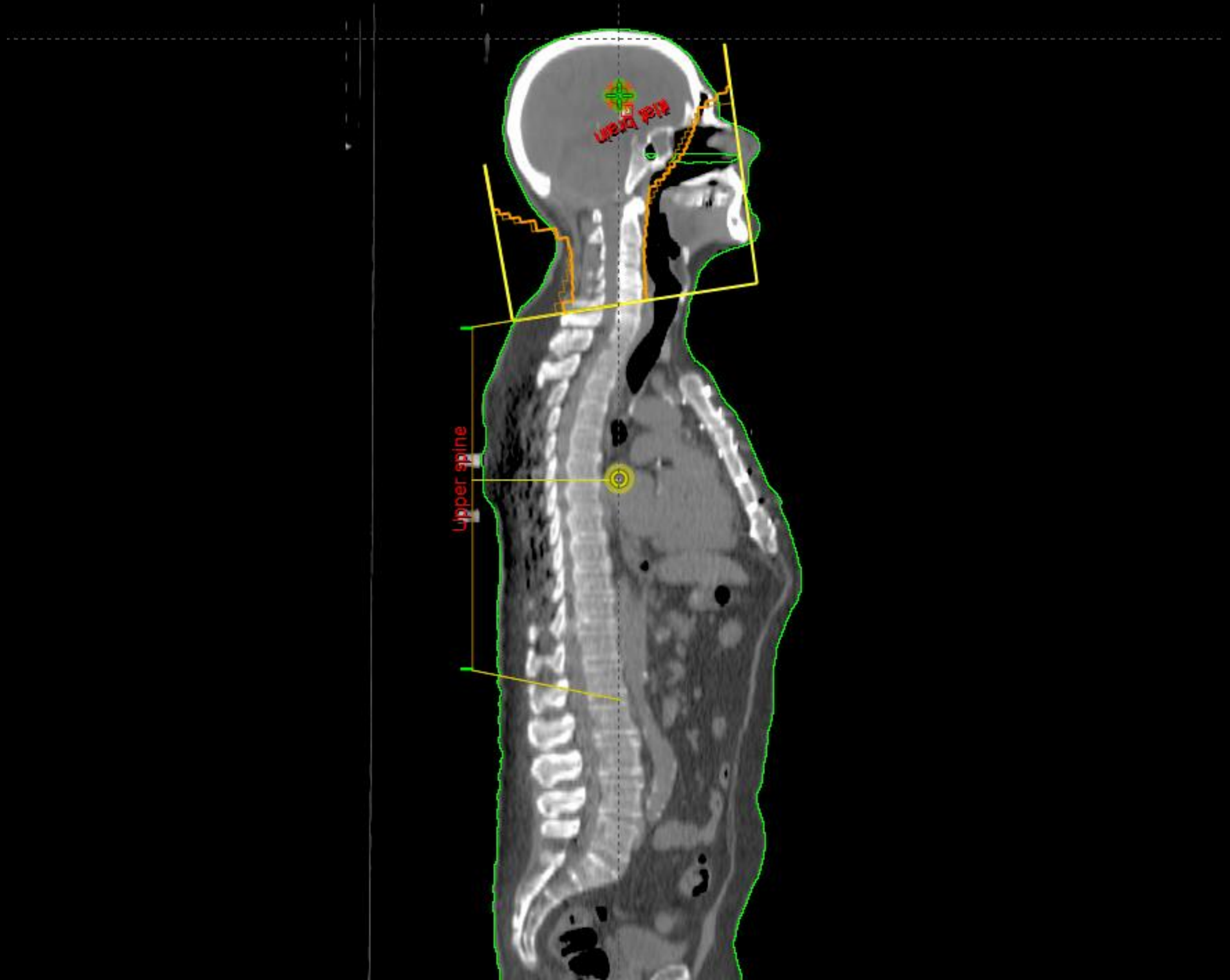


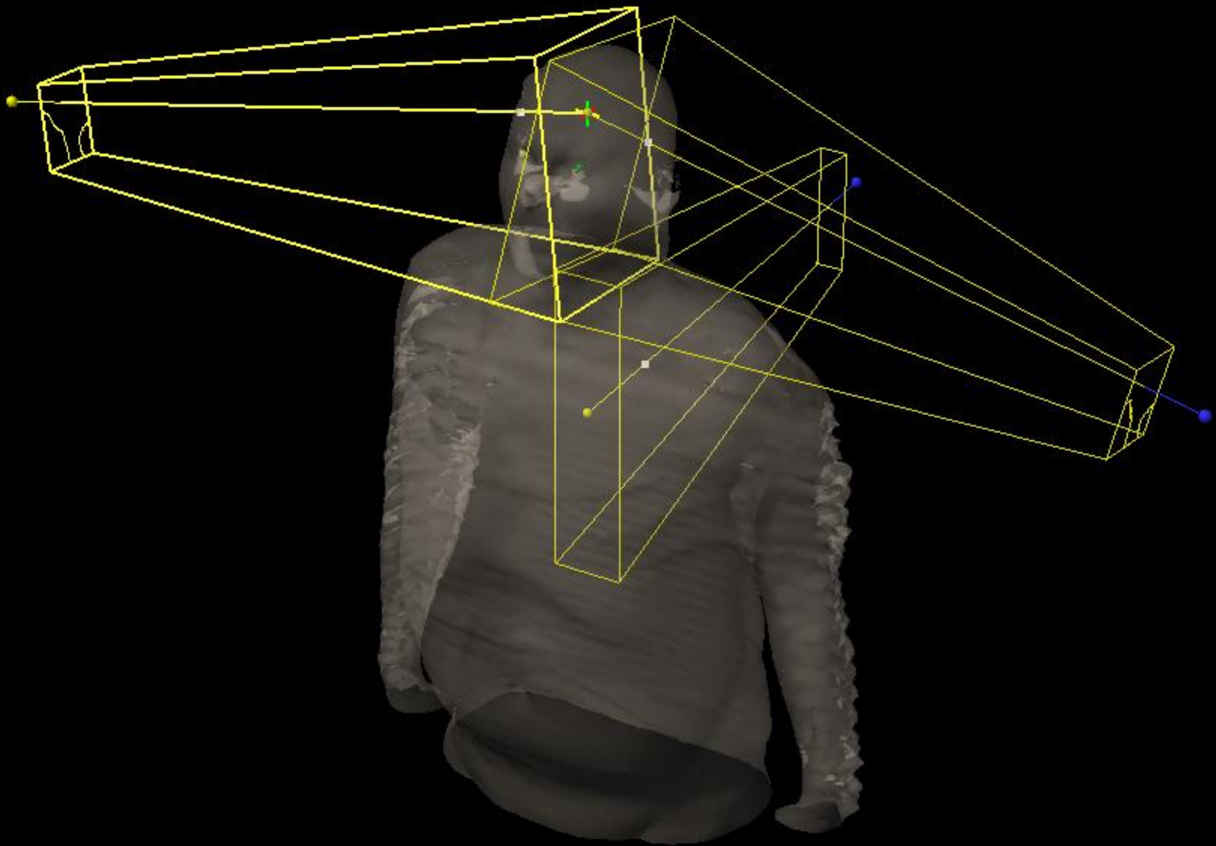


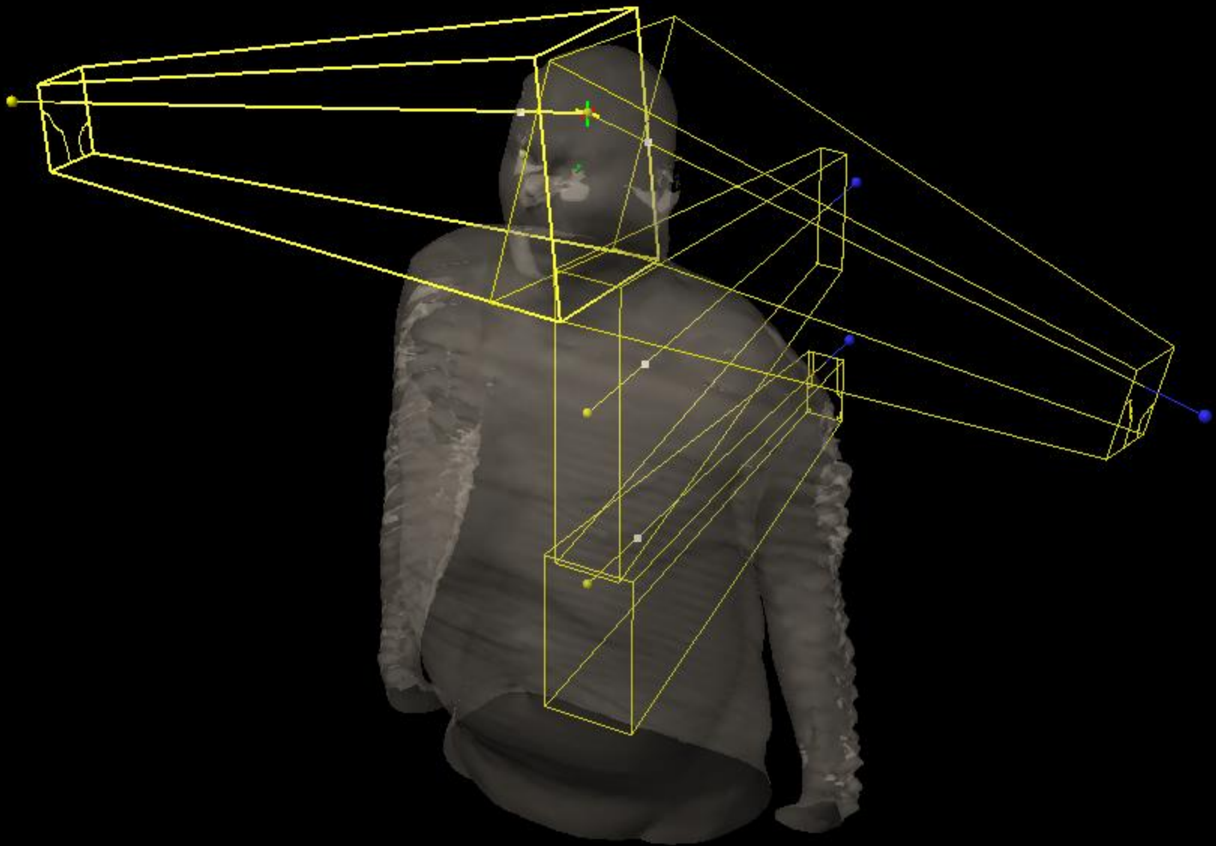





Upper spine


Mid brain
Upper spine






Upper spine
Lower spine

Field Setup

- Brain fields
  - Rotate gantry to avoid lenses
  - Set inferior border to ensure chin clearance after shifts
  - Rotate couch to match inferior borders
- Upper spinal field
  - Rotate collimator for brain fields to match spinal field
- Lower spinal field
  - Overlap with upper spinal field <u>anterior</u> of cord (avoid hotspot)

Outline

Background

Classic CSI

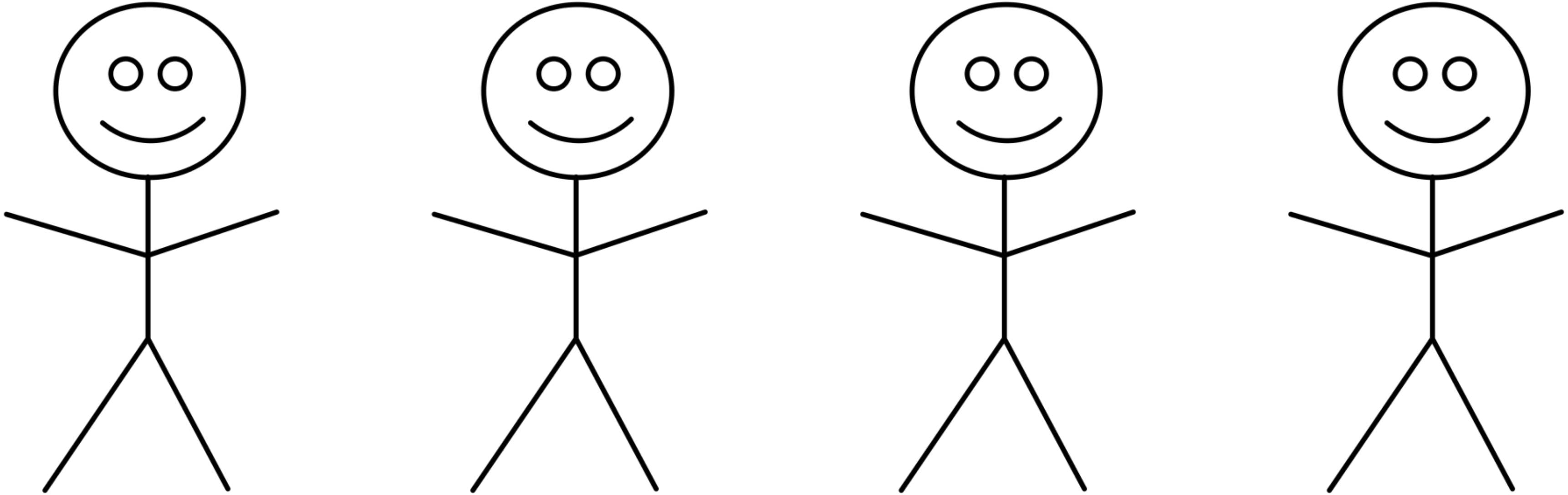
Integrated Feathering

Other CSI methods

Example

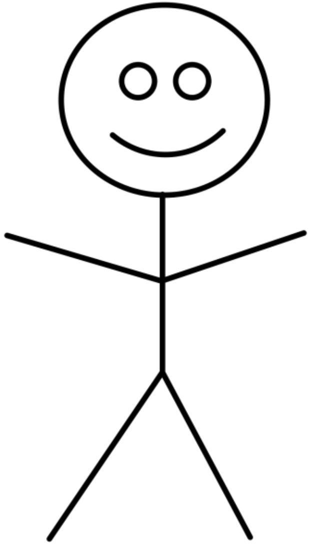
- Adult CSI patient
  - 4 fields
- 36 Gy in 18 fractions
- Feather every 6 fractions
  - 3 plans

Workload



Dosimetrist   Doctor   Physicist   Therapist

Workload

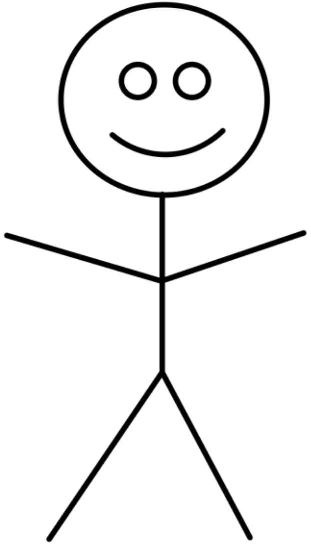


Dosimetrist

Dosimetrists have to:

- Create an additional plan for each feather
- Prepare/export multiple plans

Workload

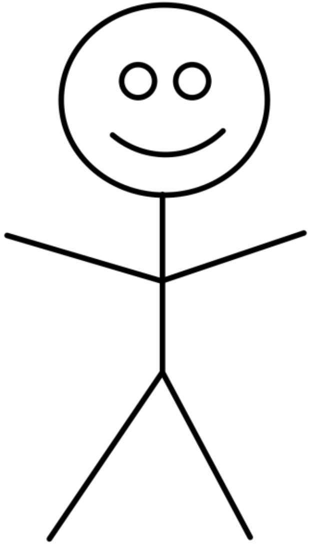


Doctor

Doctors have to:

- Approve 3 plans + composite
- Review 3 sets of port films

Workload

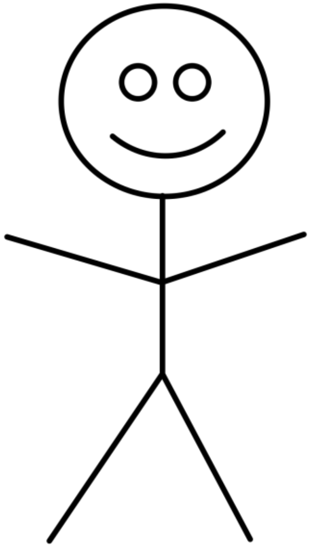


Physicist

Physicists have to:

- Check 3 different plans
- Confirm match/shift in each plan

Workload

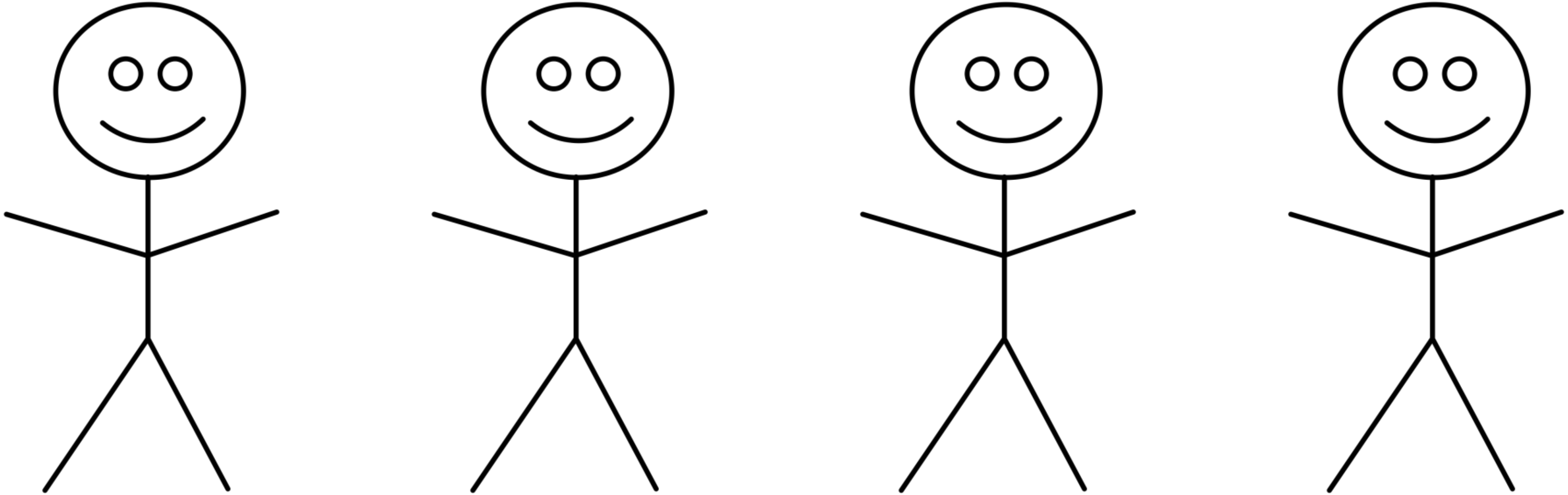


Therapist

Therapists have to:

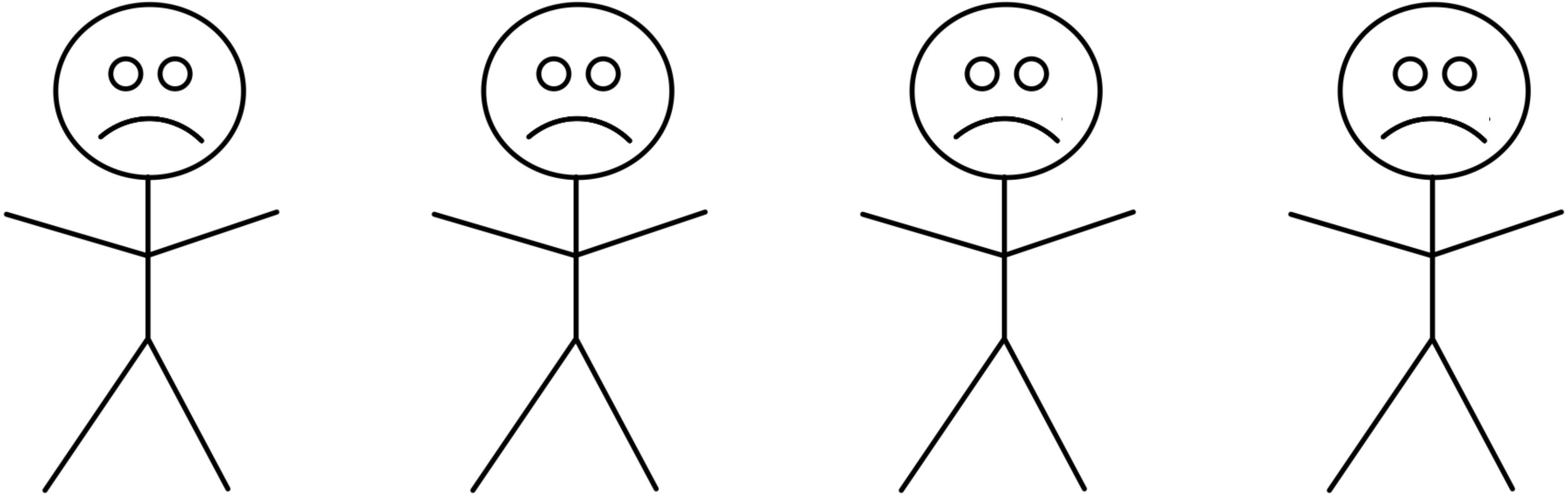
- Port film/set up patient 3 times
  - Takes up more machine time

Workload



Dosimetrist Doctor Physicist Therapist

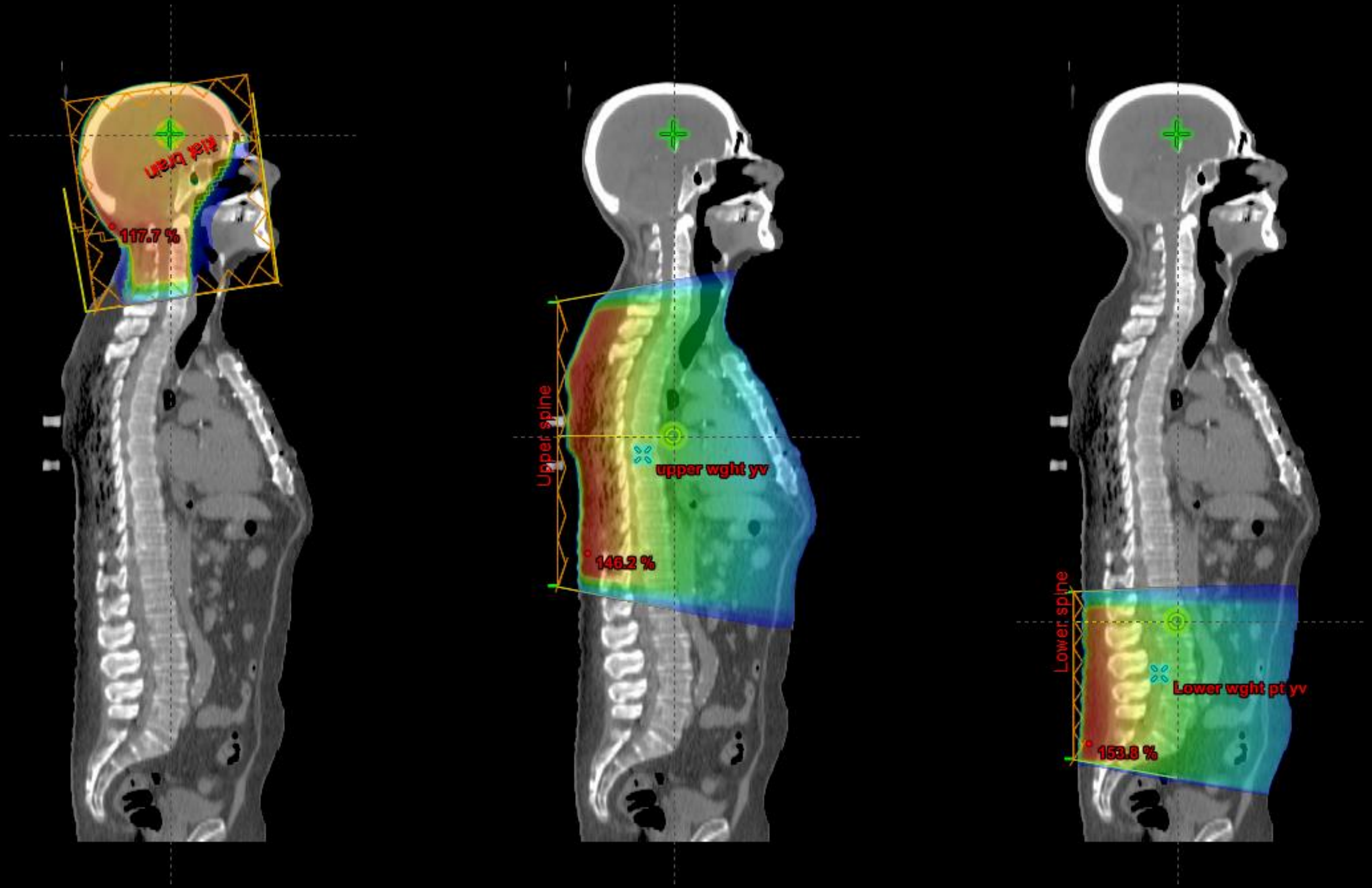
Workload



Dosimetrist Doctor Physicist Therapist

Integrated Feathering

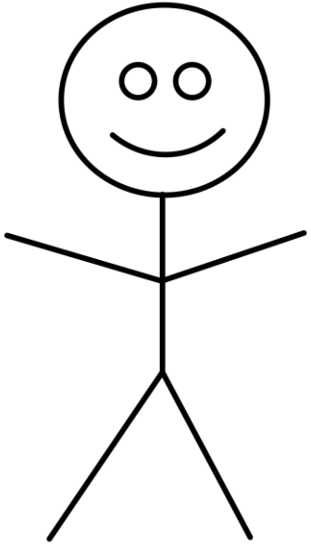
- Field-in-field beams
  - Feather across the match line region in **one plan**
  - 3 equally-weighted segments
  - 1 cm shift between segments
- Same plan throughout entire treatment


117.7 %
Upper spine
upper wght yv
146.2 %
Lower spine
Lower wght pt yv
153.8 %

Integrated Feathering

Classic Feathering

New Workload

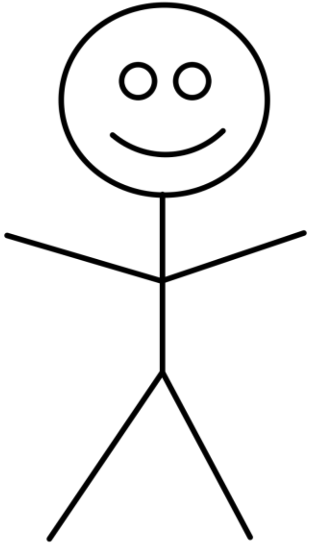


Dosimetrist

Dosimetrists have to:

- Create one field-in-field plan
  - Field matching is the longest part
  - Takes the same time as 3 plans (1 hr)
- Prepare/export one plan (30 min)
  - 1/3 less work

Workload

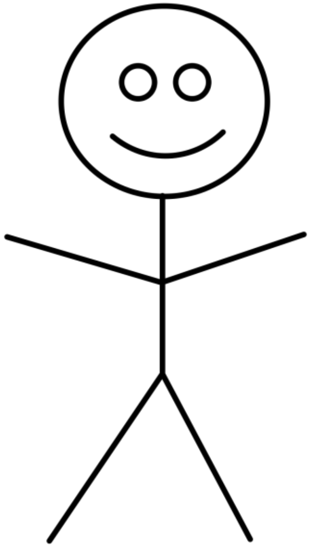


Physicist

Physicists have to:

- Check one plan
  - Learning curve
  - Should reduce plan review time

Workload


Therapist

Therapists have to:

- Port film/set up patient once
  - Same setup for each fraction
  - Less risk/room for error (safer for patient)

Treatment Schedule

Fx 1 +40 min of port film	Fx 2	Fx 3	Fx 4	Fx 5	Fx 6
Fx 7 +40 min of port film	Fx 8	Fx 9	Fx 10	Fx 11	Fx 12
Fx 13 +40 min of port film	Fx 14	Fx 15	Fx 16	Fx 17	Fx 18

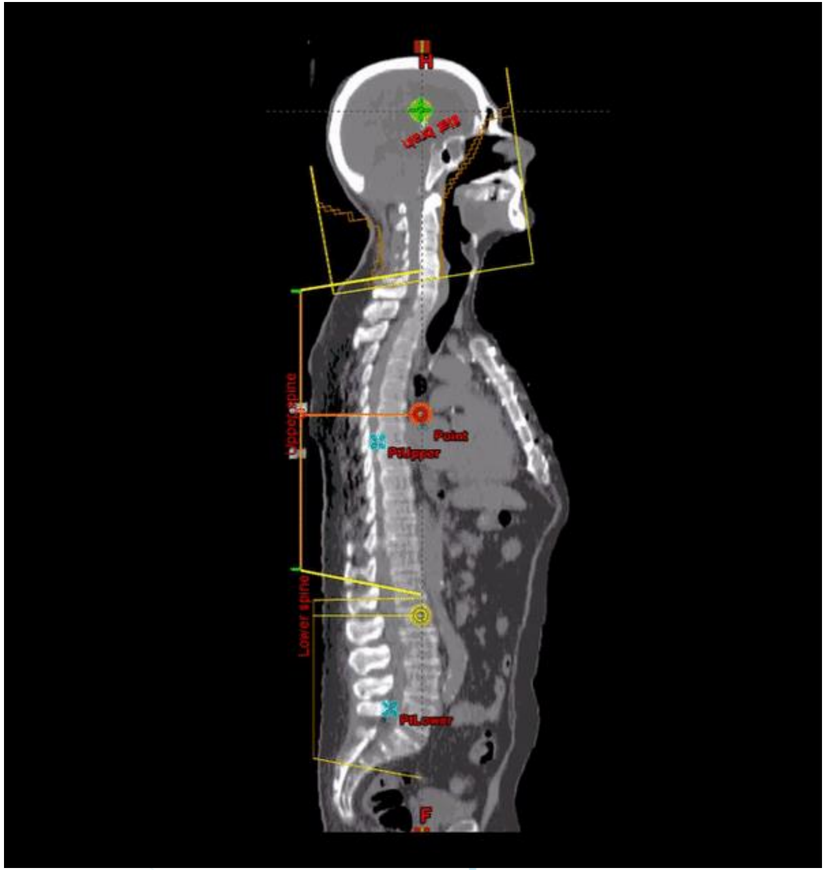
Treatment Schedule

80 min saved

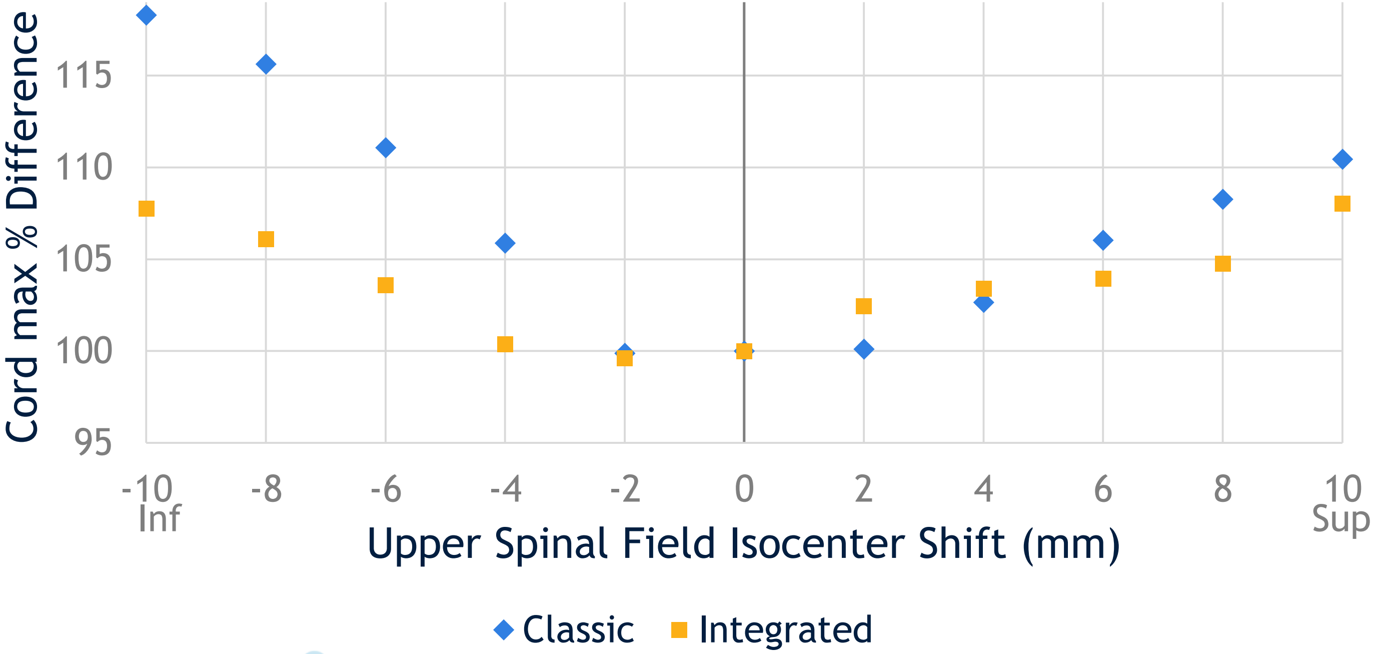
Fx 1 +39 min of port film	Fx 2	Fx 3	Fx 4	Fx 5	Fx 6
Fx 7	Fx 8	Fx 9	Fx 10	Fx 11	Fx 12
Fx 13	Fx 14	Fx 15	Fx 16	Fx 17	Fx 18

Setup Error

- Simulated isocenter setup errors of upper spinal field
  - 2 mm shifts up to 10 mm
- Classic CSI plans
  - Shifted one of the three upper spinal fields (1/3 affected)
- Integrated CSI plans
  - Shifted 1/3 fractions of upper spinal field-in-field



Setup Error



Cord max % Difference
115
110
105
100
95
-10
Inf
-8
-6
-4
-2
0
2
4
6
8
10
Sup
Upper Spinal Field Isocenter Shift (mm)
Classic
Integrated

Integrated Feathering

- Decreases staff workload
- Decreases patient time on table
- Reduces effects of potential setup errors

Outline

Background

Classic CSI

Integrated Feathering

Other CSI methods

Intensity-modulated radiation therapy and volumetric-modulated arc therapy for adult craniospinal irradiation—A comparison with traditional techniques

Matthew T. Studenski, Ph.D.,* Xinglei Shen, M.D.,* Yan Yu, Ph.D.,* Ying Xiao, Ph.D.,* Wenyin Shi, M.D.,*
Tithi Biswas, M.D.,† Maria Werner-Wasik, M.D.,* and Amy S. Harrison, M.S.*

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CSI: 3D vs. IMRT/VMAT

- 10 patients
- 36 Gy

3D

- 100 cm SSD
- Prone

IMRT

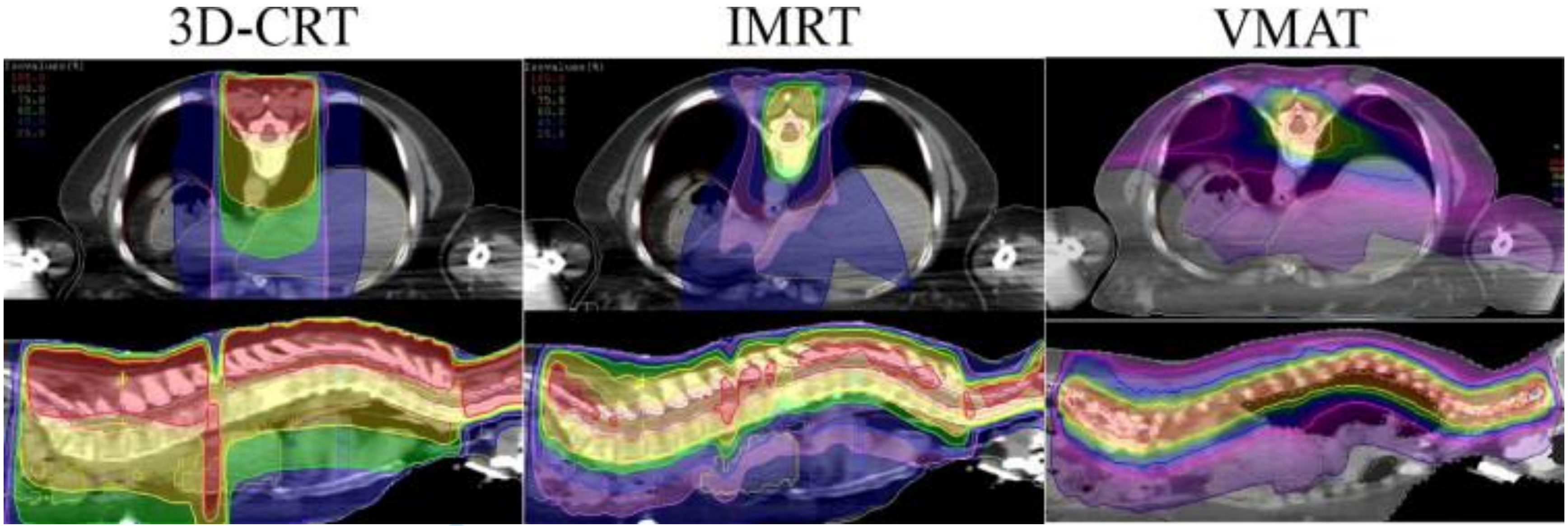
- 5-field cranial
- 5-field spinal

VMAT

- 2 full arcs cranial
- 1 200° arc spinal

Studenski, Matthew T., et al. "Intensity-modulated radiation therapy and volumetric-modulated arc therapy for adult craniospinal irradiation—a comparison with traditional techniques." Medical Dosimetry 38.1 (2013): 48-54.

CSI: 3D vs. IMRT/VMAT



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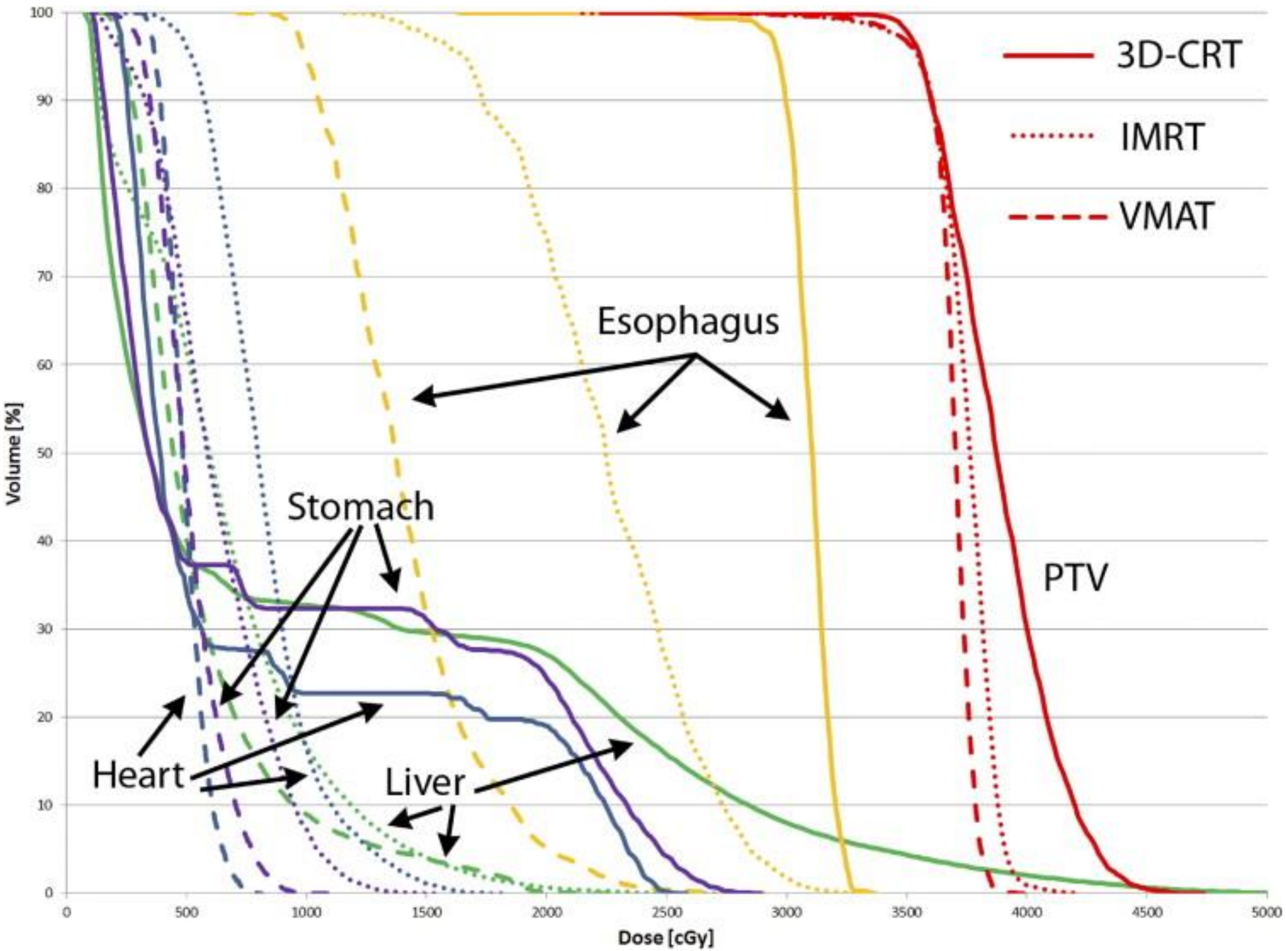

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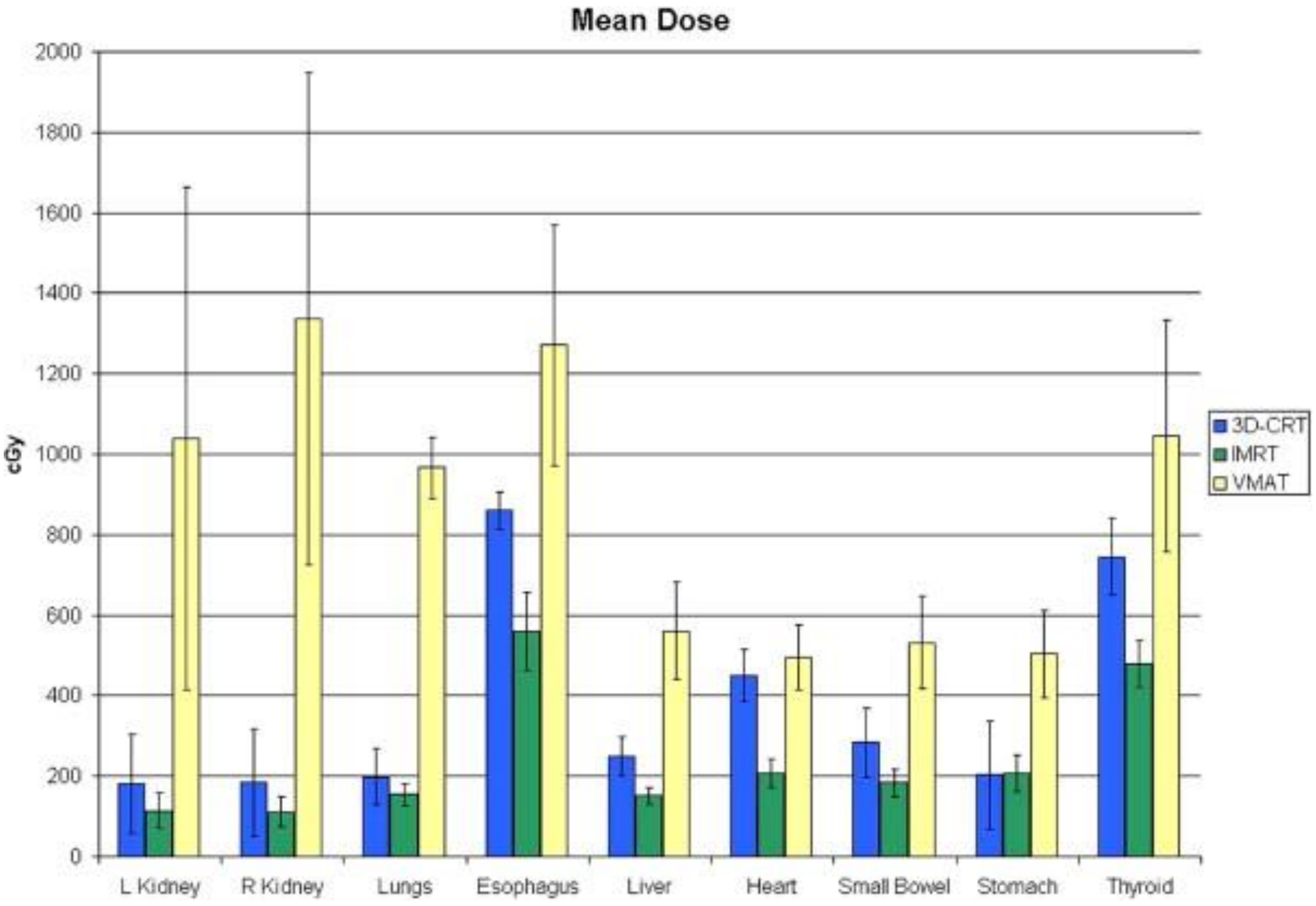

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CSI: 3D vs. IMRT/VMAT

	3D	IMRT	VMAT
Pros	• Most efficient • Negligible OAR dose increase for cranial	• OAR sparing • Target coverage	• OAR sparing • Target coverage
Cons	• Higher dose to OARs for spinal fields	• Difficult to QA junctions • Hard to control hotspots outside of PTV • Longest treatment times	• Difficult to QA junctions • Hard to control hotspots outside of PTV • Low dose spread

Studenski, Matthew T., et al. "Intensity-modulated radiation therapy and volumetric-modulated arc therapy for adult craniospinal irradiation—a comparison with traditional techniques." Medical Dosimetry 38.1 (2013): 48-54.

CRANIOSPINAL IRRADIATION TECHNIQUES: A DOSIMETRIC COMPARISON OF PROTON BEAMS WITH STANDARD AND ADVANCED PHOTON RADIOTHERAPY

Myonggeun Yoon, Ph.D.,* Dong Ho Shin, Ph.D.,* Jinsung Kim, Ph.D.,† Jong Won Kim,* Dae Woong Kim,* Sung Yong Park, Ph.D.,* Se Byeong Lee, Ph.D.,* Joo Young Kim, M.D.,* Hyeon-Jin Park, M.D.,‡ Byung_Kiu Park, M.D.,‡ and Sang Hoon Shin, M.D.§

*Proton Therapy Center, National Cancer Center, Goyang, Korea; †Department of Radiation Oncology, Samsung Medical Center, Seoul, Korea; ‡Pediatric Oncology Clinic, Center for Specific Organs Cancer, National Cancer Center, Goyang, Korea; and §Neuro-Oncology Clinic, Center for Specific Organs Cancer, National Cancer Center, Goyang, Korea

CSI: Proton vs. Photon

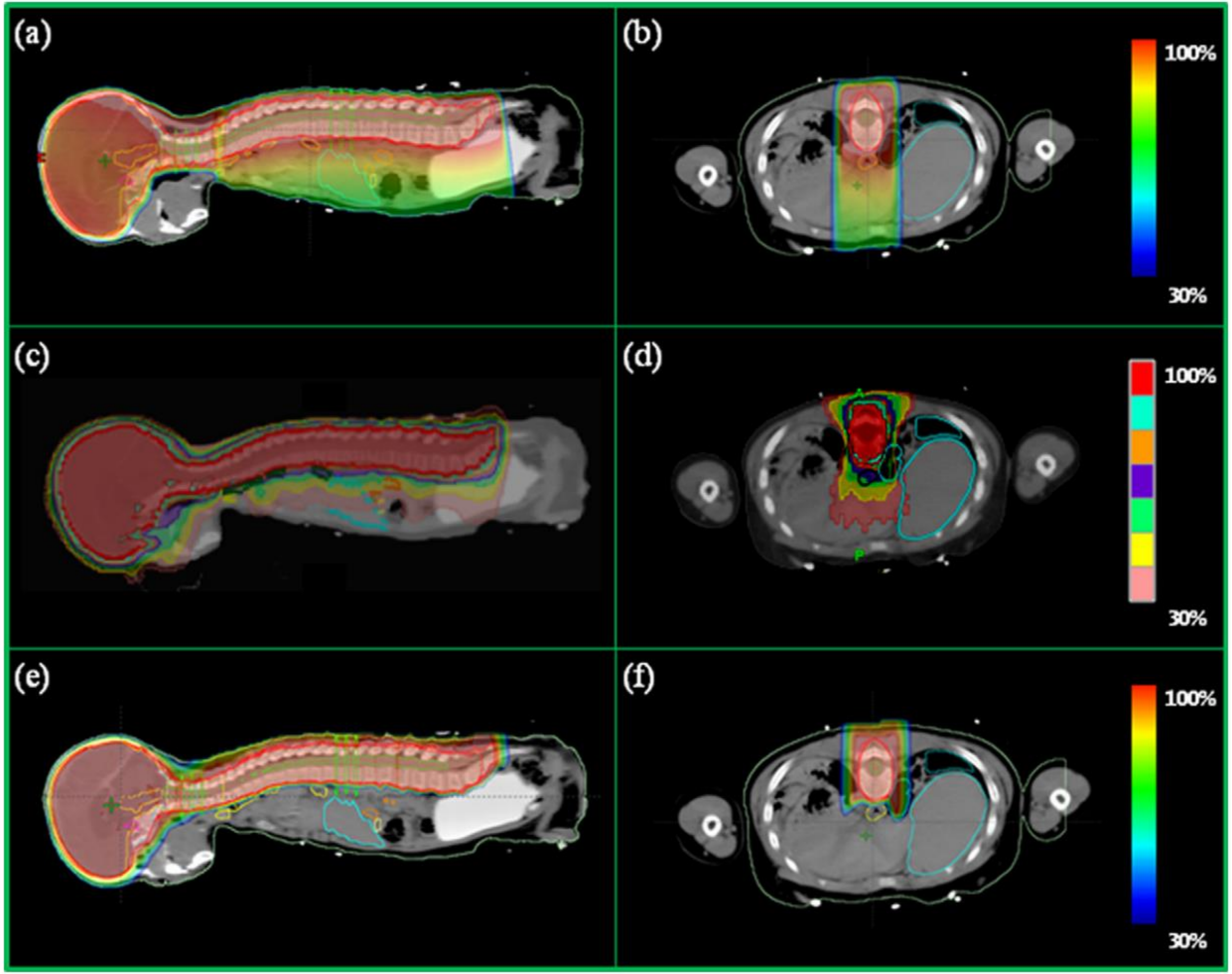
- 10 patients
- 1.8 Gy x 20 fractions = 36 Gy
- Three plans:
  1. 3D
  2. Tomotherapy
  3. Proton

Yoon, Myonggeun, et al. "Craniospinal irradiation techniques: a dosimetric comparison of proton beams with standard and advanced photon radiotherapy." International Journal of Radiation Oncology* Biology* Physics 81.3 (2011): 637-646.

3D

Tomotherapy

Proton



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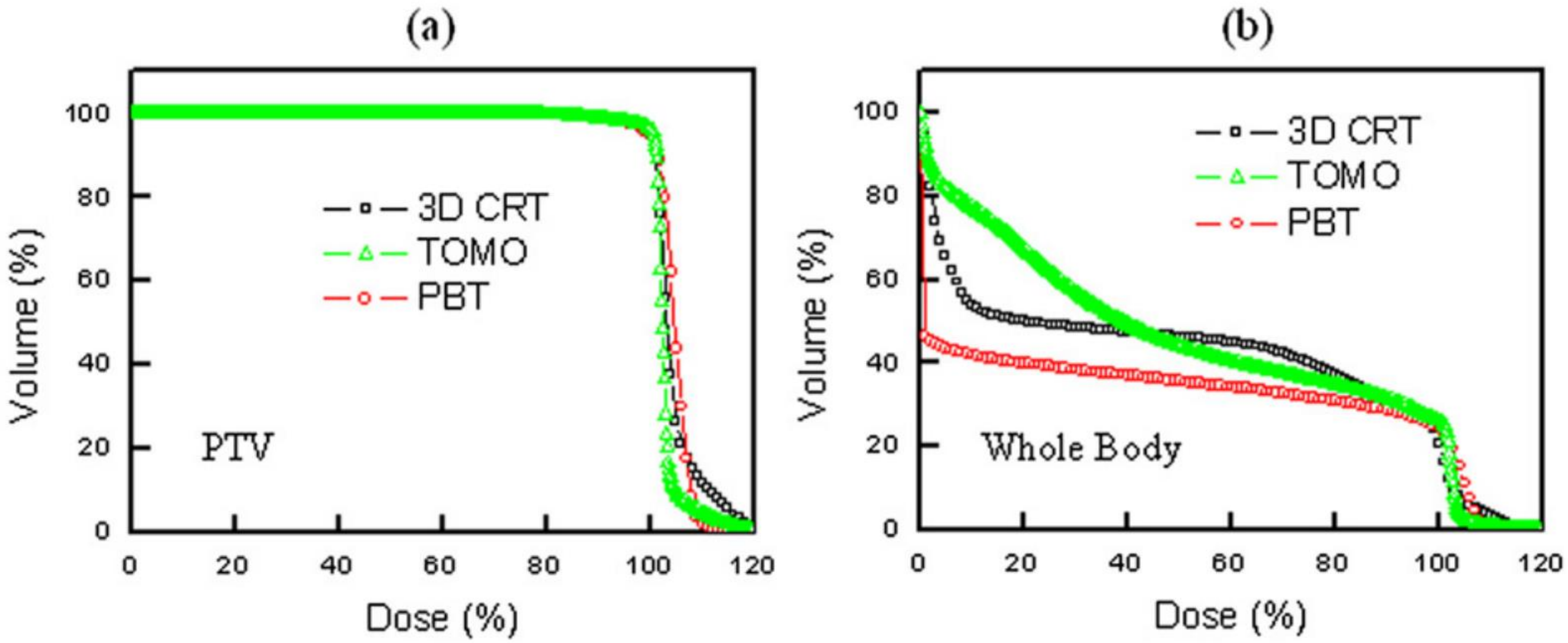

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Proton Beam Craniospinal Irradiation Reduces Acute Toxicity for Adults With Medulloblastoma

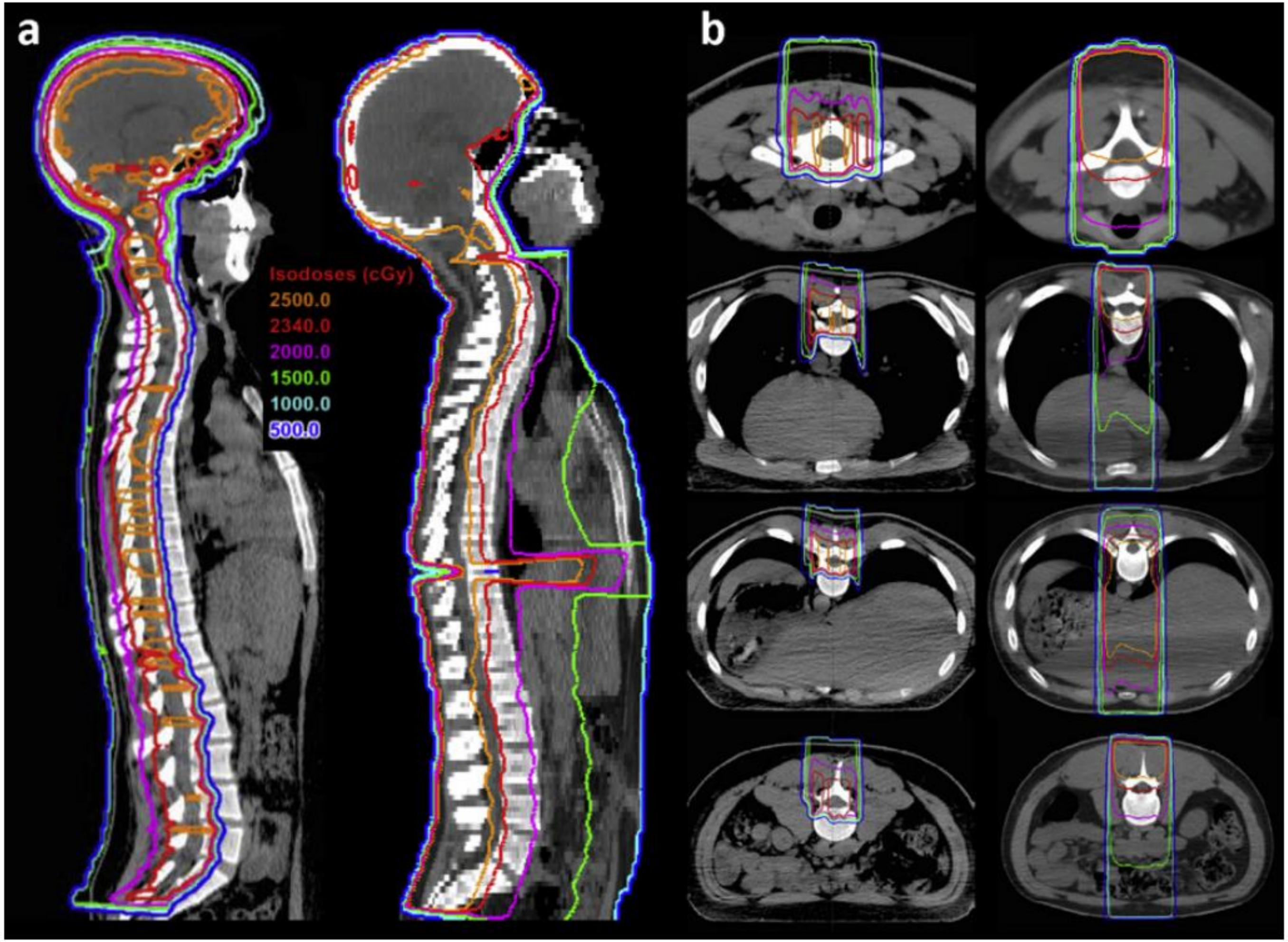
Aaron P. Brown, MD,* Christian L. Barney, BS,|| David R. Grosshans, MD, PhD,* Mary Frances McAleer, MD, PhD,* John F. de Groot, MD,† Vinay K. Puduvalli, MD,† Susan L. Tucker, PhD,‡ Cody N. Crawford, CMD,* Meena Khan, CMD,* Soumen Khatua, MD,§ Mark R. Gilbert, MD,† Paul D. Brown, MD,* and Anita Mahajan, MD*

*Departments of *Radiation Oncology, †Neuro-Oncology, ‡Bioinformatics and Computational Biology, and §Pediatric Oncology, The University of Texas MD Anderson Cancer Center, Houston, Texas; and ||Baylor College of Medicine, Houston, Texas*

CSI: Proton vs. Photon

- 21 treated with photon
  - Classic CSI
- 19 treated with proton
  - Supine
  - Similar beam arrangements
  - Vertebral body-sparing with proton range

Brown, Aaron P., et al. "Proton beam craniospinal irradiation reduces acute toxicity for adults with medulloblastoma." International Journal of Radiation Oncology* Biology* Physics 86.2 (2013): 277-284.



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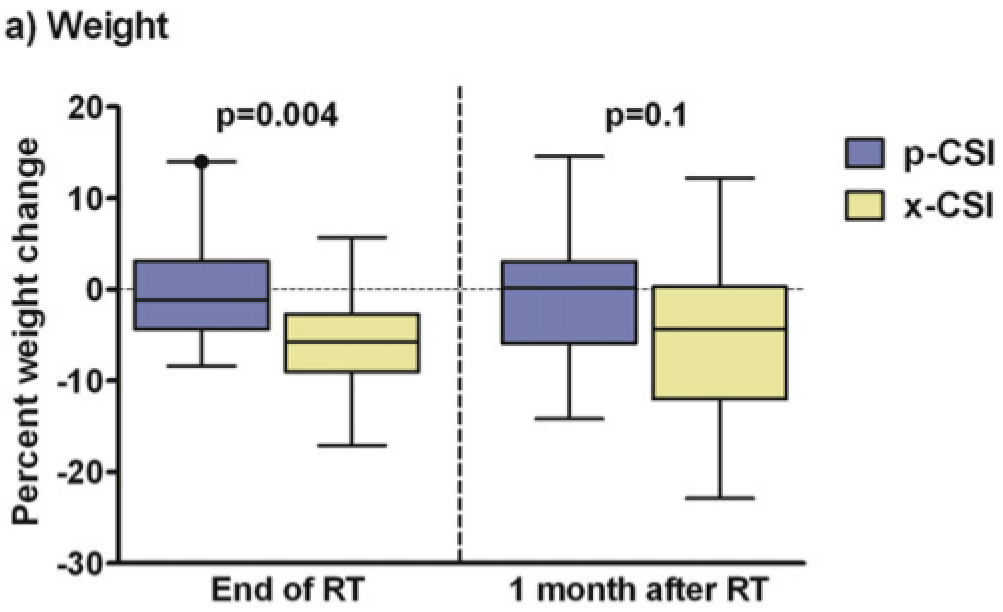
CSI: Proton vs. Photon



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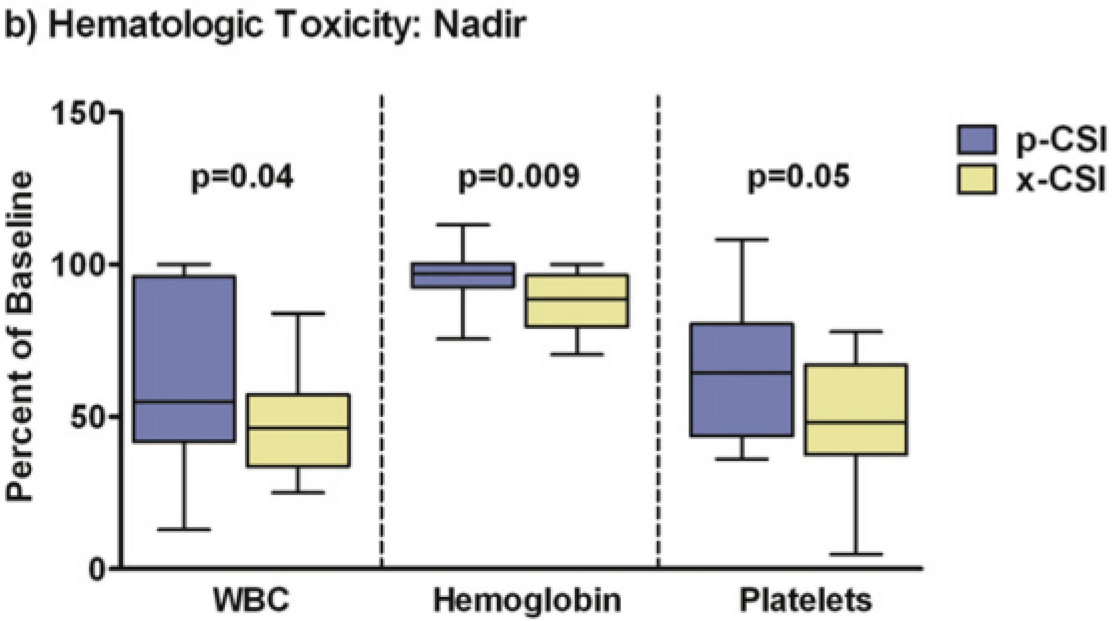
CSI: Proton vs. Photon



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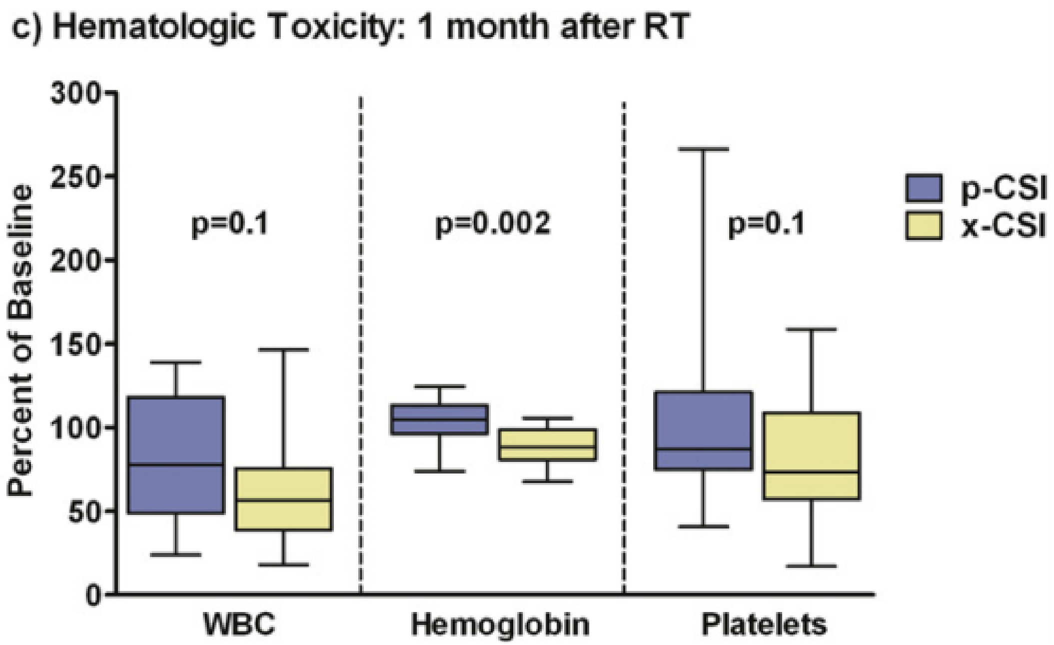

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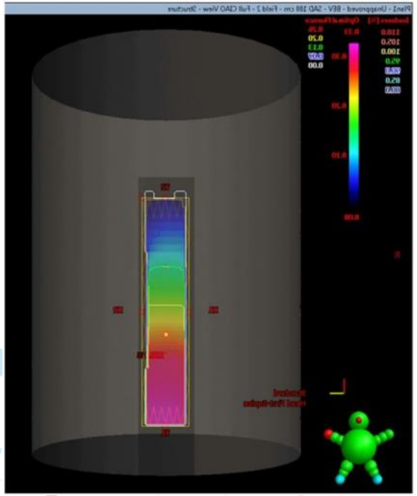
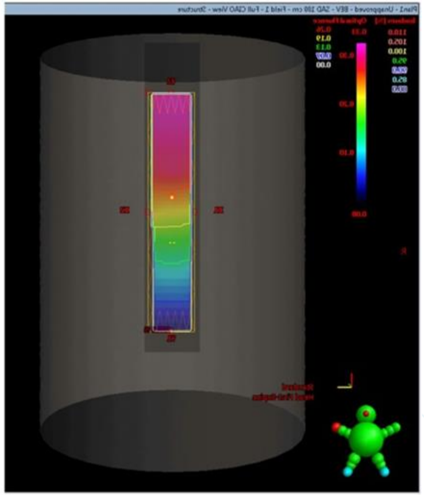
Proton CSI

- Dosimetry (Yoon et al)
  - Lower OAR organ equivalent doses
  - Significantly lower dose to the chest/abdomen
  - Similar dose to head & neck area
- Clinical outcomes (Brown et al)
  - Less acute gastrointestinal toxicities (nausea/vomiting)
  - Less hematologic toxicities
- Limited availability

Varian Auto-Feathering

- Eclipse v15.5
- Only for inverse optimized plans
- Controls hot and cold spots at junction





Magliari, V. MyVarian webinar 2018

Take-Home Points

- Review math/geometry for CSI calculations
- Gantry, collimator, and couch rotations to match brain fields
- Integrated feathering ☺
- IMRT/VMAT CSI
- Protons CSI

Thanks!

Sidney Kimmel Cancer Center
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Until every cancer is cured