ICRU 83: Clinician's Perspective

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- Learning objective
  - Ability to compare salient data points and clinical issues in IMRT Plans using ICRU 83
  - Choose from multiple plans to suit clinical objective

Planning Workflow

- Immobilization
- Image acquisition and registration

• Contouring • Constraints	Physician's Responsibility: *To interpret the plan in light of ICRU 83*
• Planning	
• Plan evaluation	

- Plan implementation

Planning Workflow

- Immobilization
- Image acquisition and registration
- Contouring
- Constraints
- Planning
- **Plan evaluation**
- Plan implementation

To choose the best among multiple plans:

- Target coverage
- OAR sparing
- Hotspot/Coldspot
- DVH analysis
- Isodose coverage
- Indices (CI & HI)
- Clinical relevance

Objective Assessment

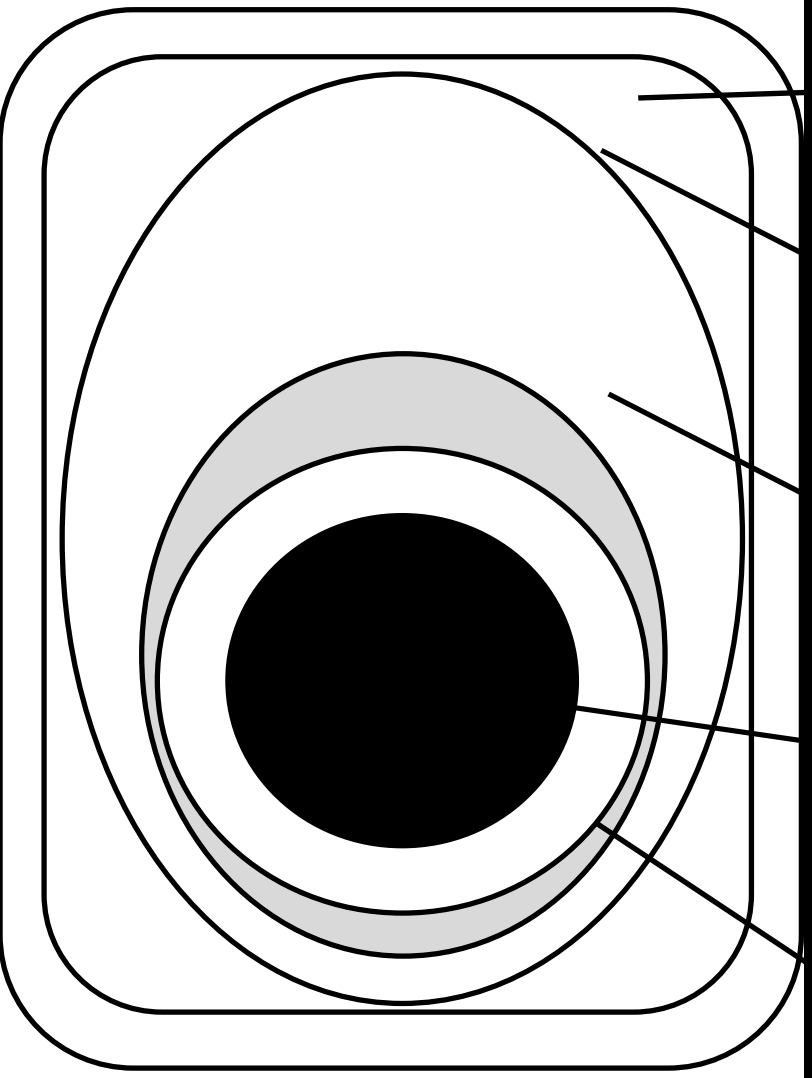
- Dose Volume Histogram
  - Cumulative
  - Differential
- Defined Volumes
  - GTV: Gross Tumor Volume
  - CTV: Clinical Target Volume
  - ITV: Internal Target Volume
  - PTV: Planning Target Volume
  - ❖ OAR: Organs @ Risk
  - ❖ PRV: Planning Vol @ Risk
  - ❖ RVR: Residual Vol @ Risk

Discretionary/ Evolving

- Assessment of isodose every slice coverage for clinical relevance
- Multimodality Images
- Biological Volumes
- Effect of variation in dose levels
- TCP/ NTCP

International Commission on Radiation Units & Measurements (ICRU)

RVR: Residual Vol @ Risk Body contour – (CTV + OAR)



TV: Volume apart from PTV receiving clinically significant dose

PTV: Set up errors & organ motion

ITV: Uncertainities of shape, size and position

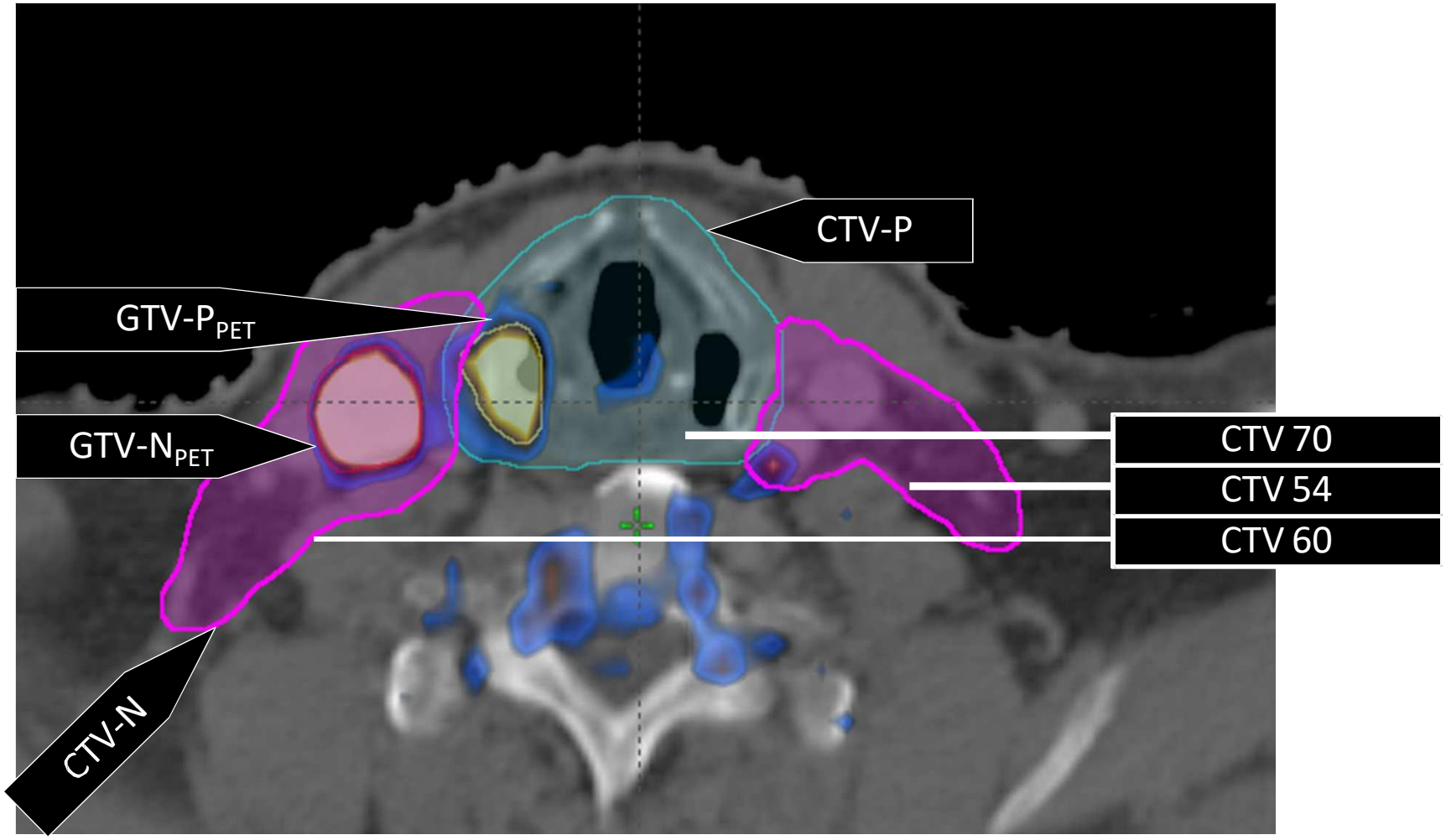
GTV: Clinically or radiologically assessed tumor (GTV-P / GTV-N)

CTV: Subclinical Extension (CTV-P / CTV-N)

Organ@ Risk (OAR)
Serial: Sp Cord Parallel: Parotid

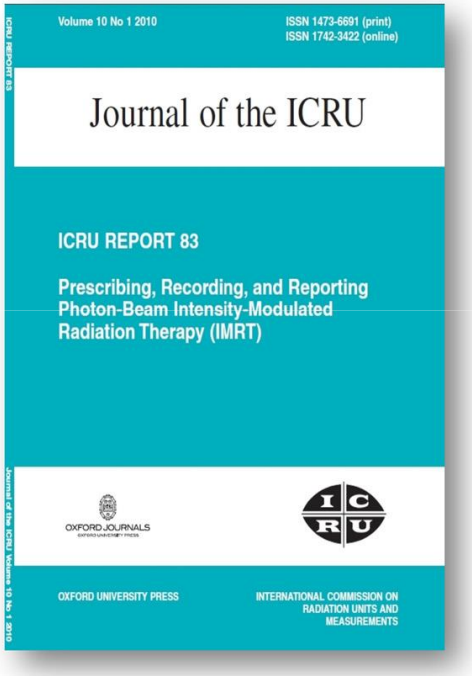
PRV:Planning Organ @ Risk Volume
OAR + Set up Margin

Types of CTV/PTV



ICRU through the ages

The new
ICRU Report 83



ICRU through ages

ICRU 29 (1974)	ICRU 50 (1993)	ICRU 62 (1999)	ICRU 83 (2010)
Target Volume	GTV	GTV	GTV
	CTV	CTV	CTV
		ITV	ITV
	PTV	PTV	PTV
Treatment volume	Treated volume	Treated volume	Treated volume
Irradiated volume	Irradiated volume	Irradiated volume	Irradiated volume
Organ at Risk	Organ at risk	Organ at risk	Organ at risk
		PRV	PRV
			RVR
Hotspot (more than 100%- 2 sq cm)	Hotspot (more than 100% - 15 mm dia)	Hotspot (more than 100% - 15 mm dia)	High dose to RVR
Dose heterogenity (no values)	Dose heterogenity (+7 to -5 %)	Dose heterogenity (+7 to -5 %)	Not specified

Dose Reporting in 3D (ICRU 50)

- Dose must be reported to the ICRU reference point
  - ICRU reference point is usually isocenter
  - It could be a point in the center of the PTV
  - Uniform dose to PTV (-5 to +7%)

  Maximum & minimum dose must be reported in PTV

  Whenever possible dose should be reported to PRV

Paradigm Shift with IMRT

IMRT represents a paradigm shift

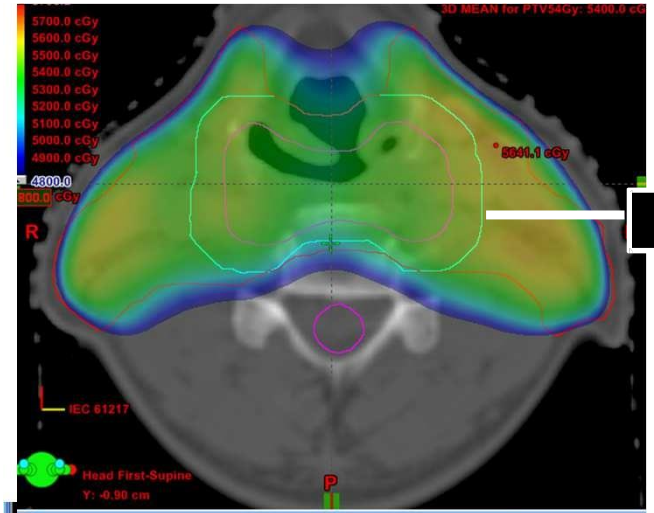
Non uniform dose (dose painting)

Large dosimetric variations

Isocenter dose is meaningless

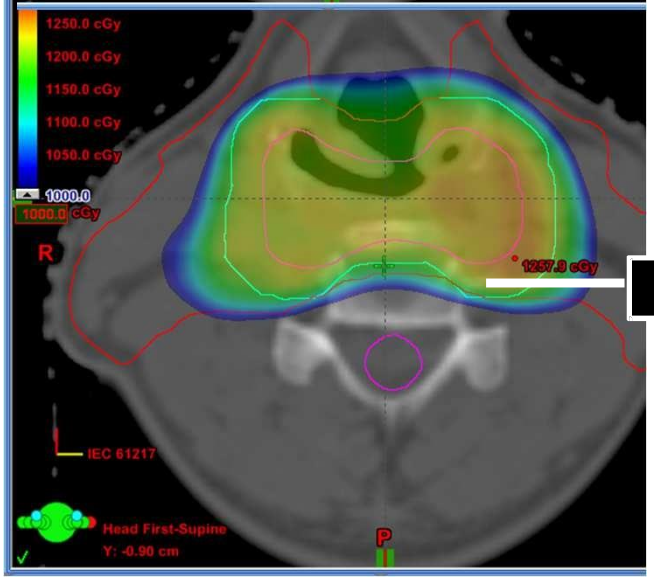
Radiobiological consequence of large heterogeneous dose is uncertain (i.e 180c Gy/day versus 250c Gy/day)

IMRT: Sequential



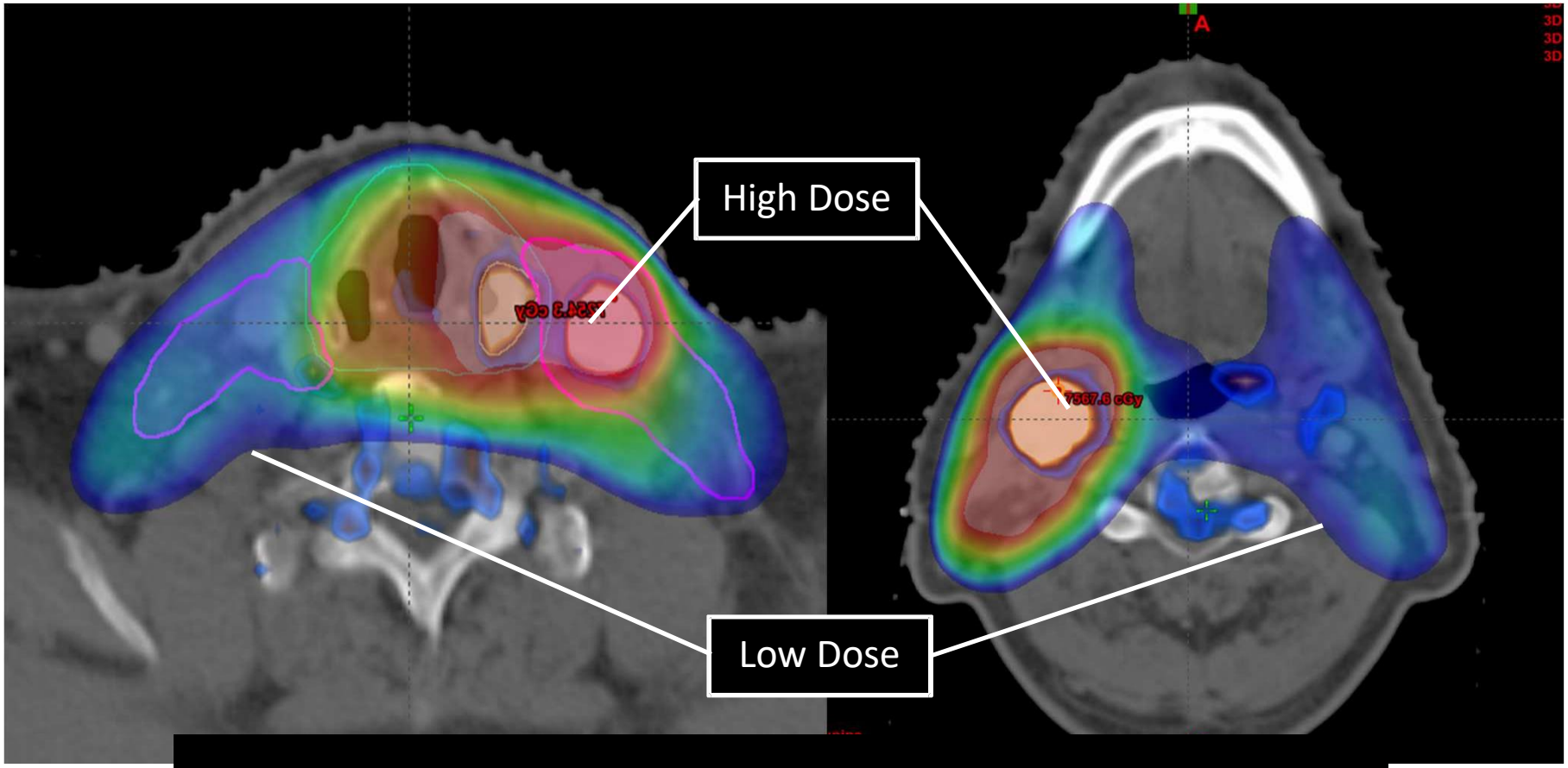
Phase I: Low Dose: Nodal+ Primary

Summation of Both Plans



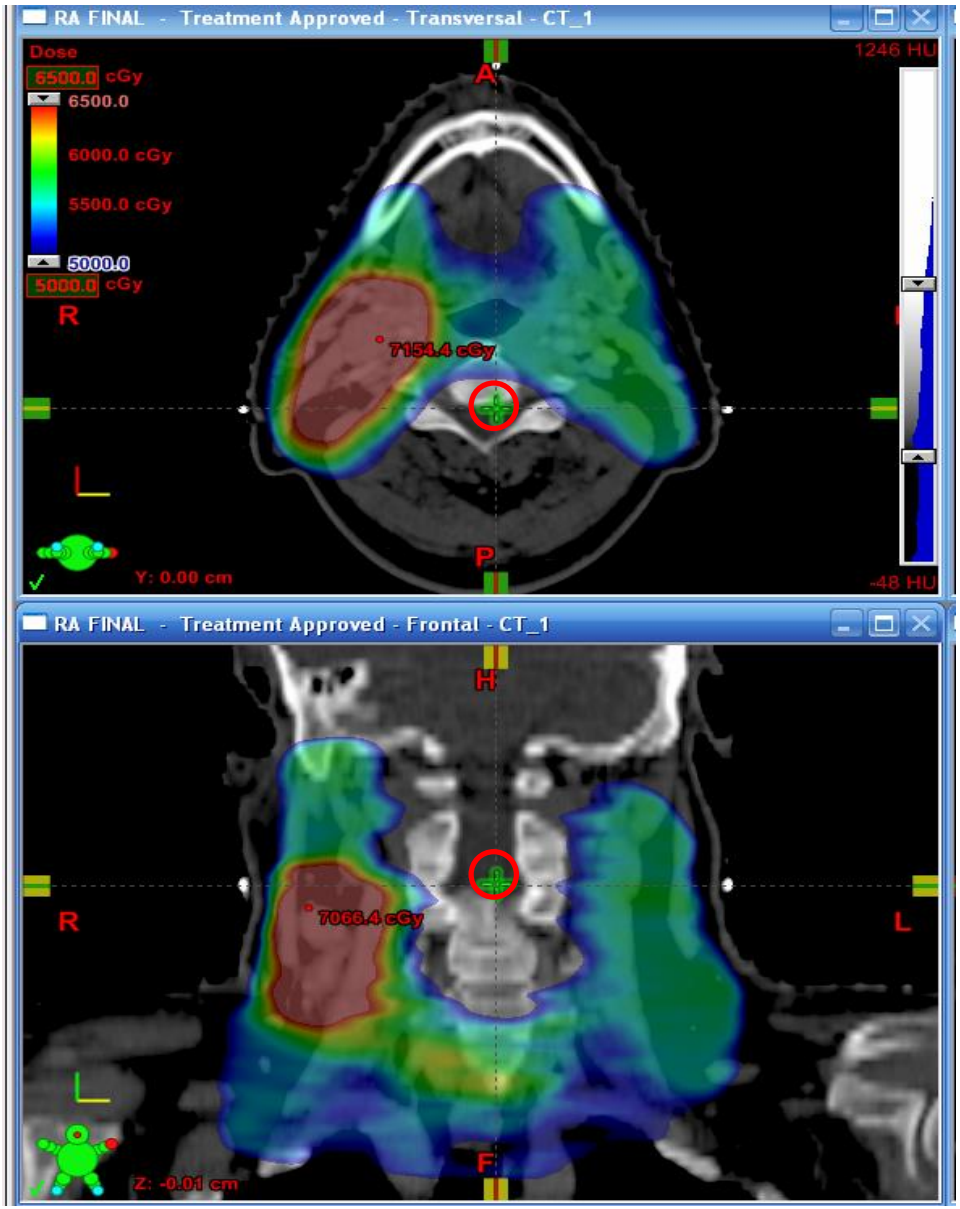
Phase II: HighDose: Primary / Boost

IMRT: Simultaneous Integrated Boost

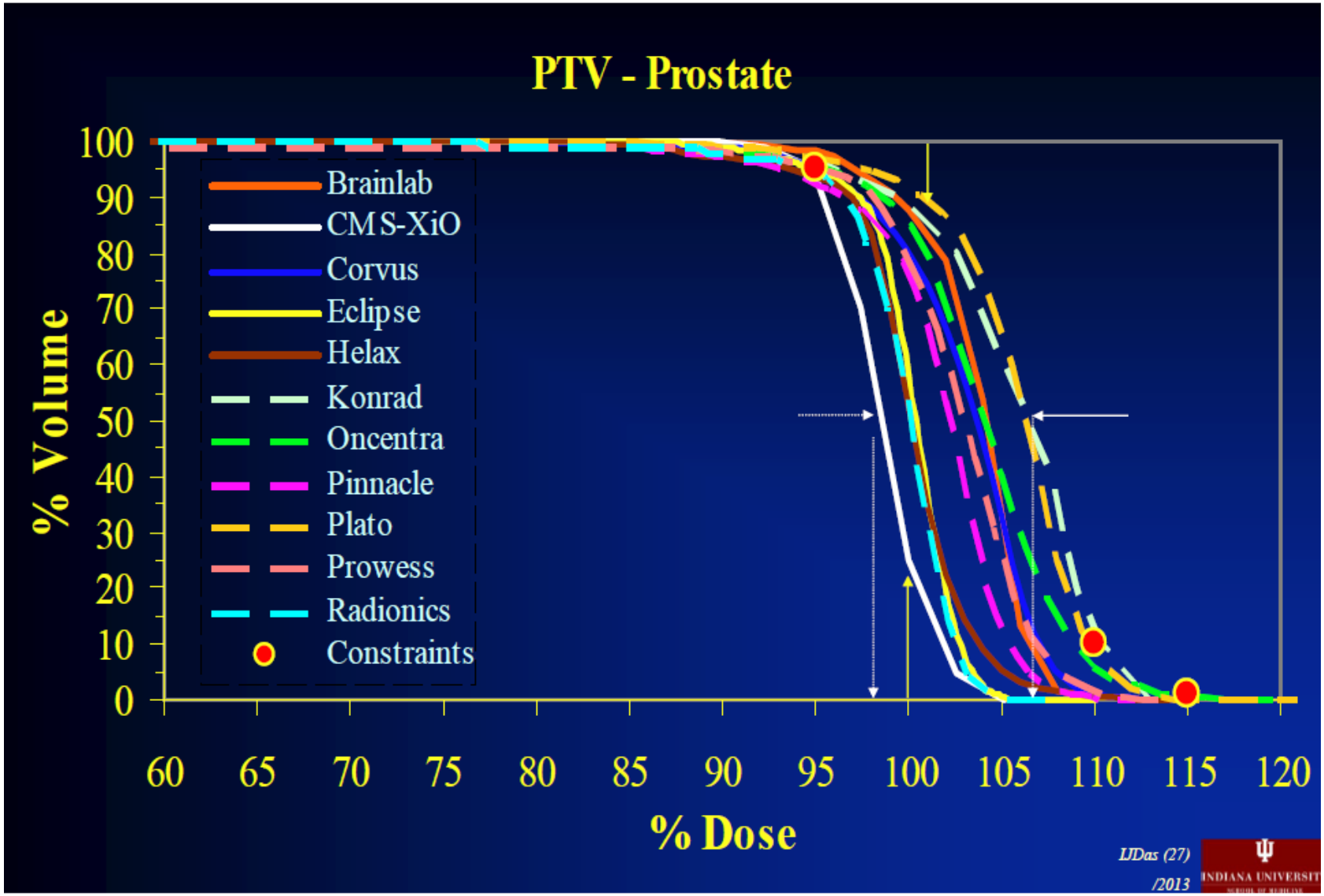


Both Low Dose & High Dose Volumes Treated Simultaneously

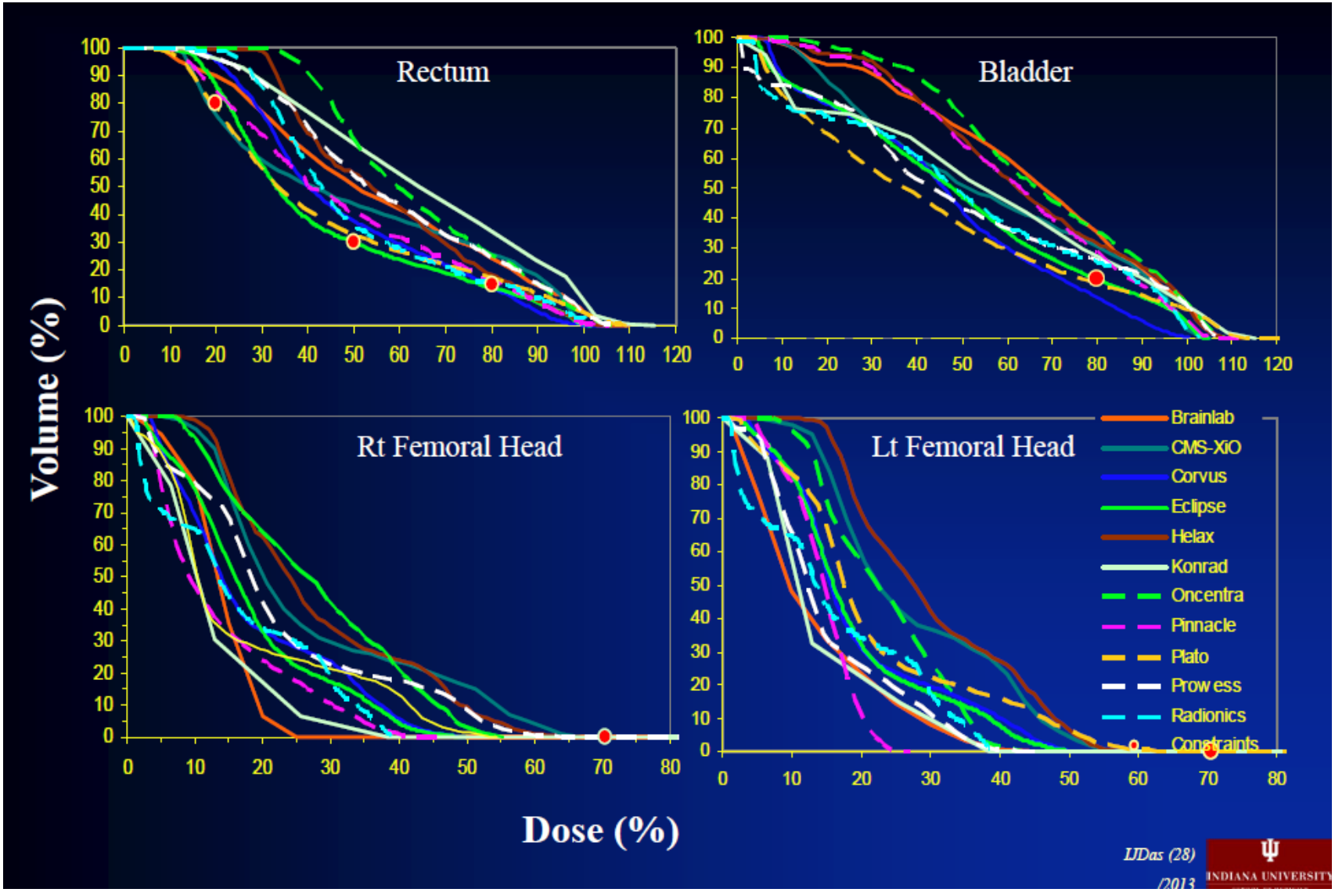
Isocenter dose is non-reprsentative



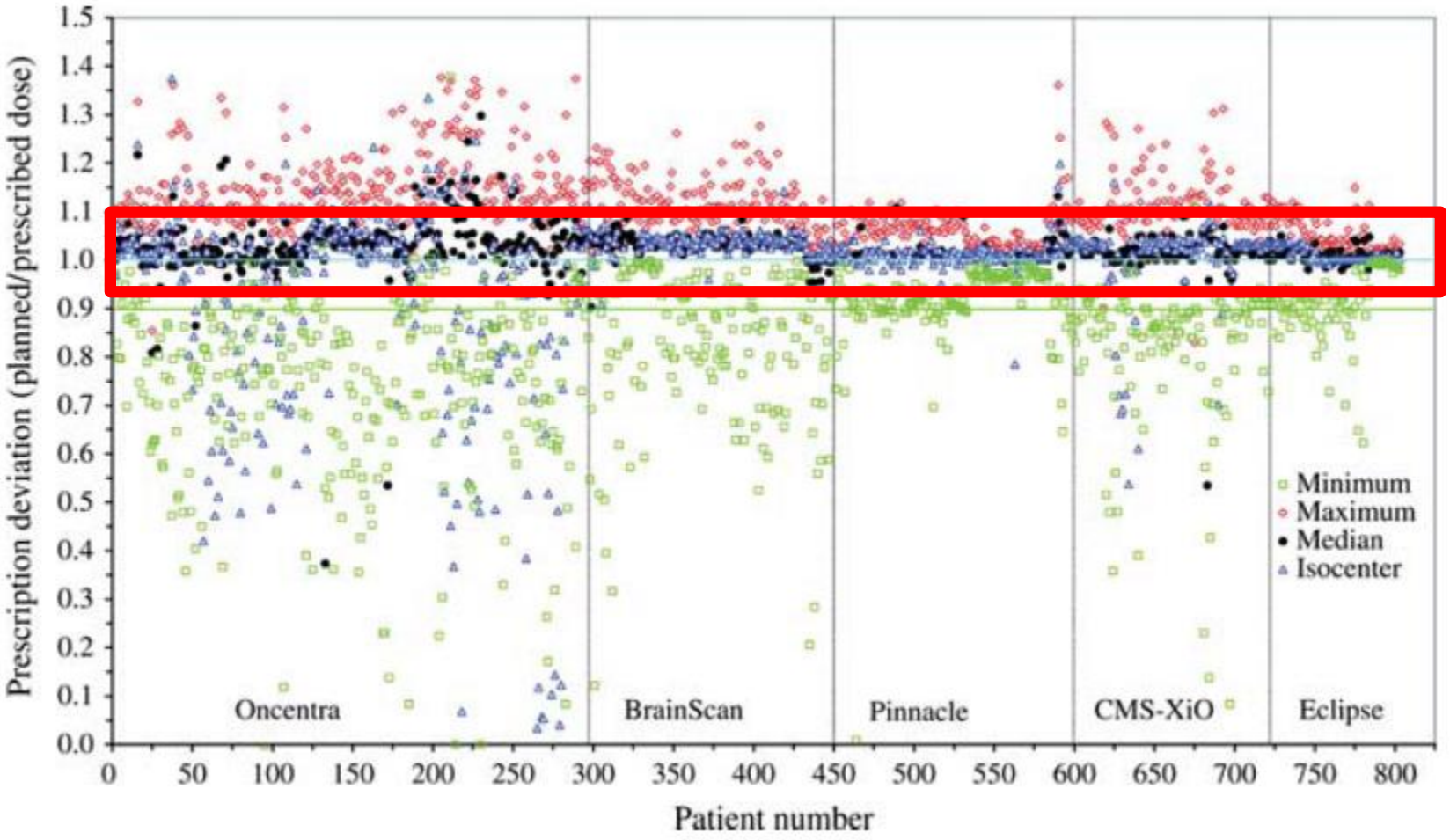
IMRT: Variability in PTV Dose



IMRT: Variability in OAR Dose



Variation of doses among 850 patients in 5 Institutions

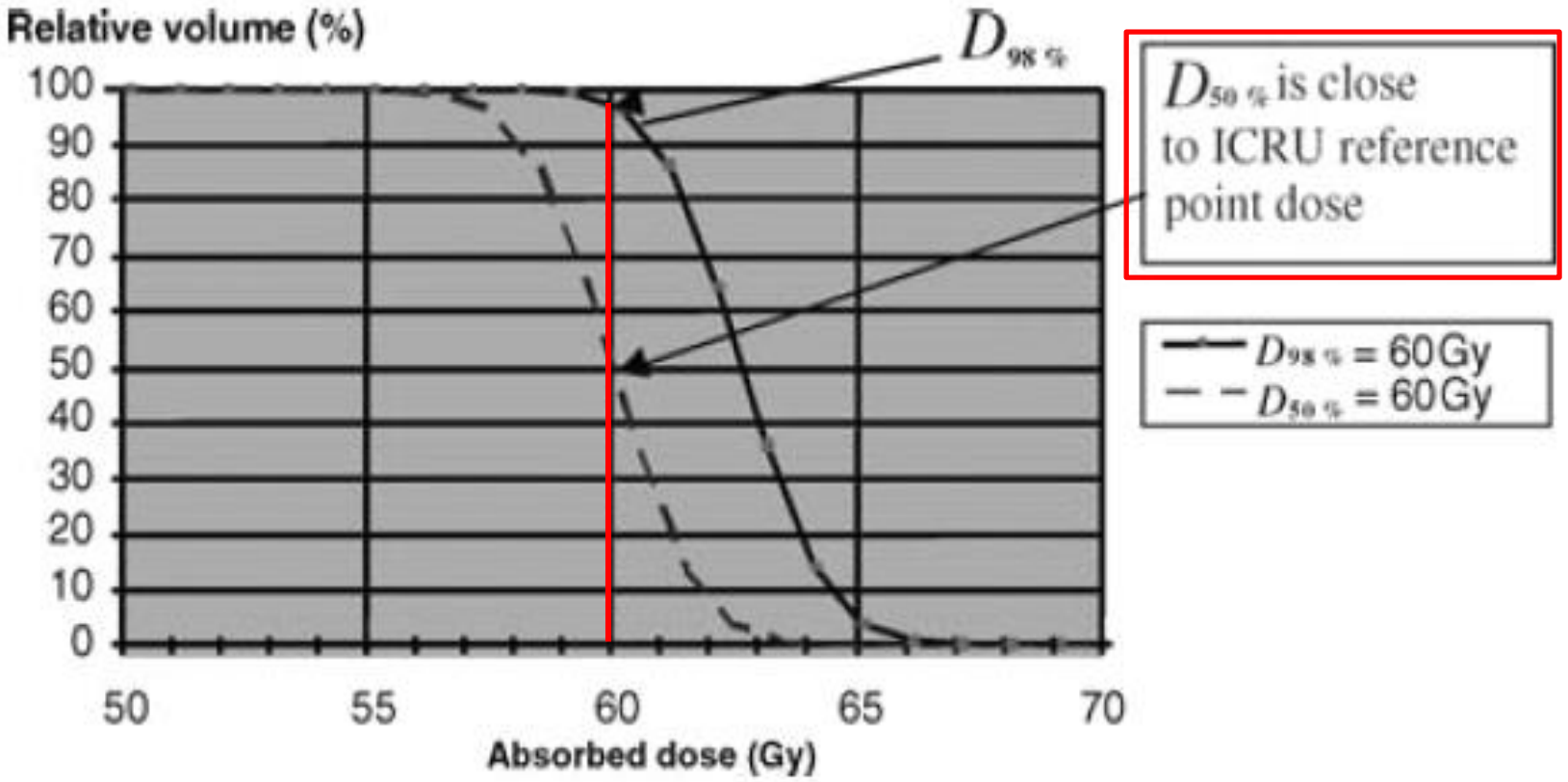


Median Dose is most consistent

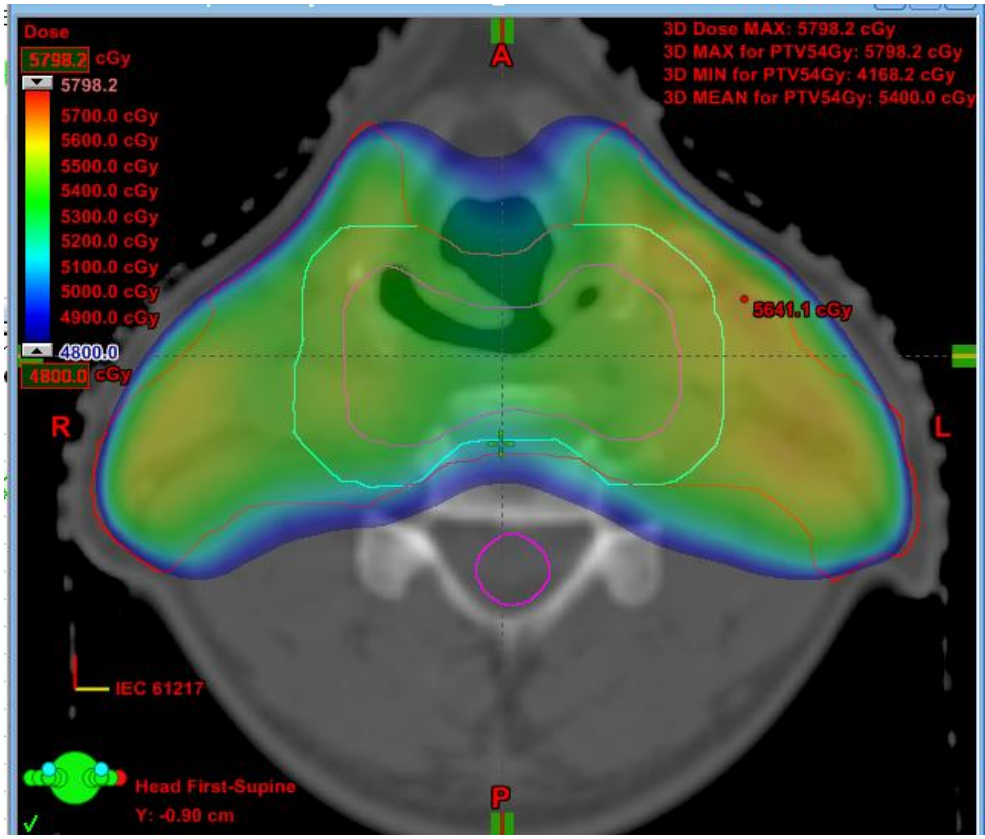
ICRU-83: PTV

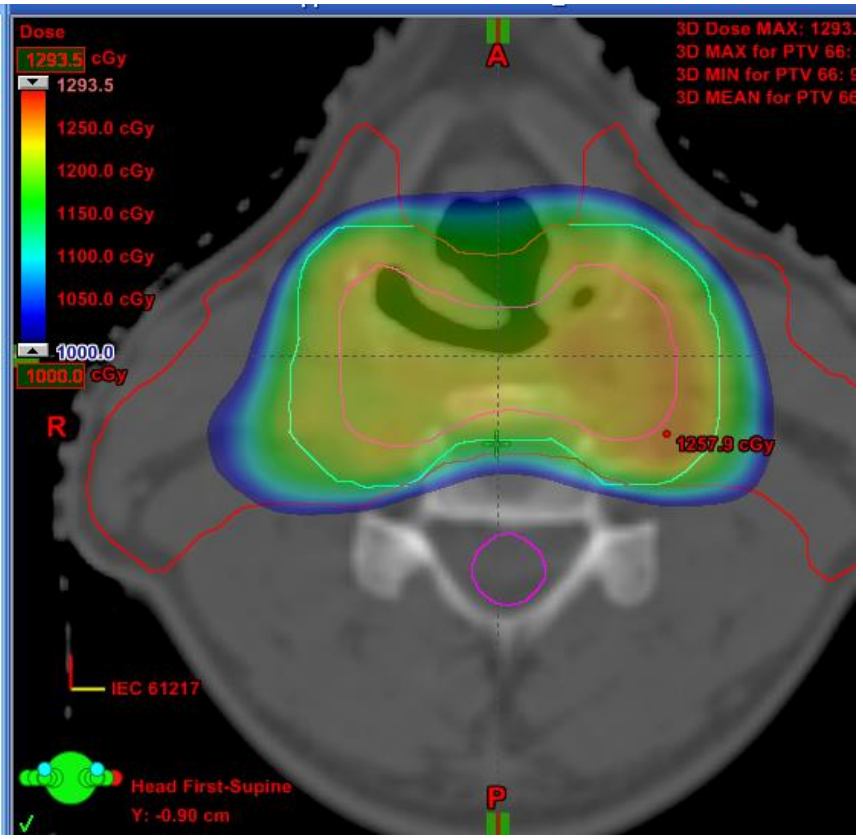
- Dose Volume Reporting
  - $D_{50\%}$ (Median Dose)
    - Most representative of prescribed dose
  - $D_{\text{mean is nearly identical to }} D_{50\%}$
  - $D_{98\%}$ (Near Minimum Dose)
    - Dose received by 98% of PTV
  - $D_{2\%}$ (Near Maximum Dose)
    - Dose received by 2% of PTV

Comparison of ICRU reference point dose to $D_{98\%}$

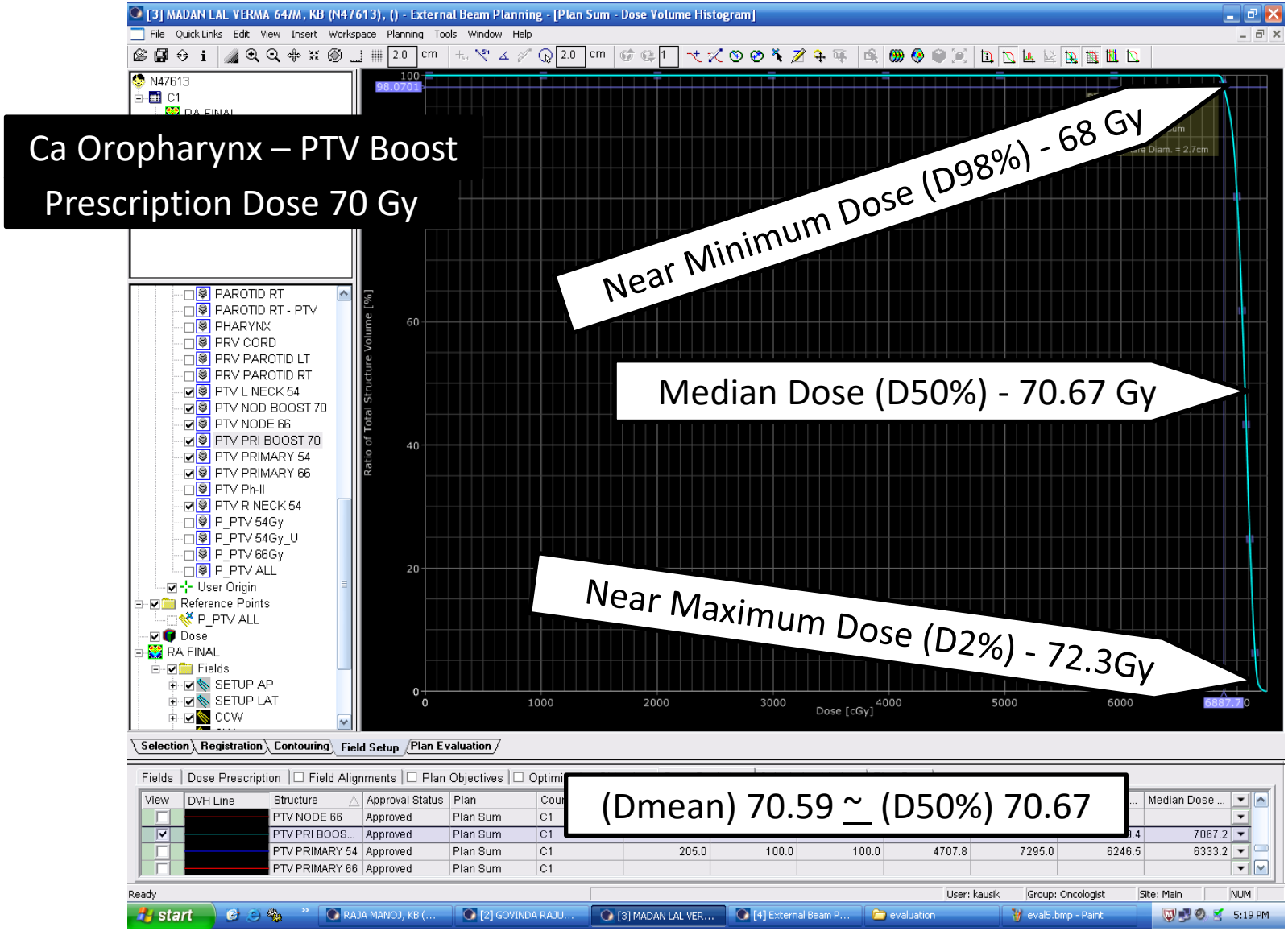


Application of ICRU 83 in single dose level plans



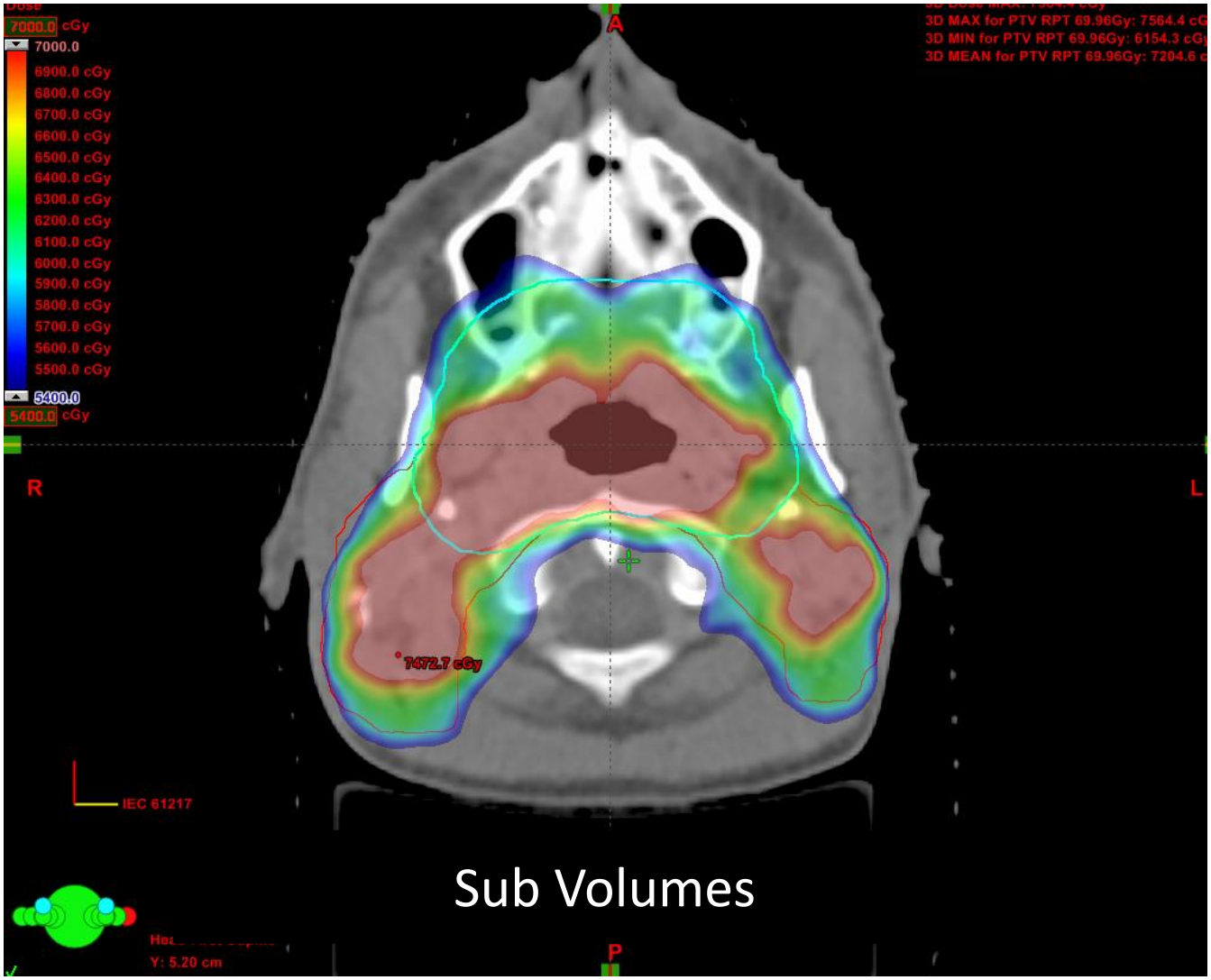


DVH of PTV


[3] MADAN LAL VERMA 64/M, KB (N47613), () - External Beam Planning - [Plan Sum - Dose Volume Histogram]
Ca Oropharynx – PTV Boost
Prescription Dose 70 Gy
Near Minimum Dose (D98%) - 68 Gy
Median Dose (D50%) - 70.67 Gy
Near Maximum Dose (D2%) - 72.3Gy
Ratio of Total Structure Volume [%]
Dose [cGy]
(Dmean) 70.59 ~ (D50%) 70.67

Multiple dose level plan:

Nasopharynx with SIB (60Gy & 70Gy in 33Fr)

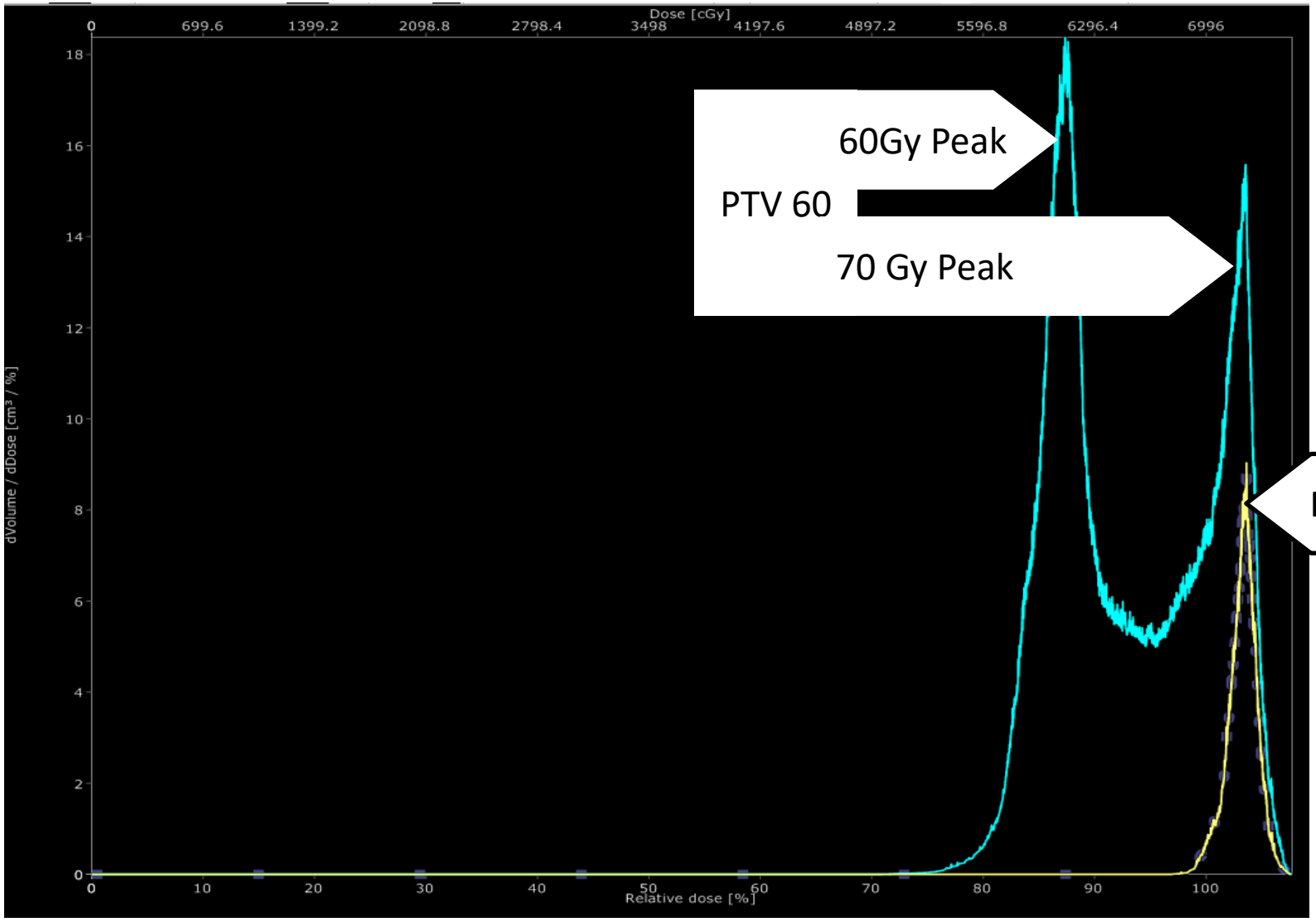


Sub Volumes

DVH of PTV


Dose [cGy]
0
699.6
1399.2
2098.8
2798.4
3498
4197.6
4897.2
5596.8
6296.4
6996
Ratio of Total Structure Volume [%]
100
90
80
70
60
50
40
30
20
10
0
Relative dose [%]
0
10
20
30
40
50
60
70
80
90
100
PTV 70
PTV 60

Differential DVH



OAR & PRV

- Serial Organs: Spinal Cord, Esophagus
  - $D_{2\%}$ is important
  - Entire organ should be considered if possible
  - Minimum dimension of 15mm to be considered.
- Parallel organs: Parotid, Liver, Lung
  - D_{mean} is important
  - D_{mean} and D_{median} may not be same
- V_d in cases like Lungs (V_{20})

TOLERANCE OF NORMAL TISSUE TO THERAPEUTIC IRRADIATION

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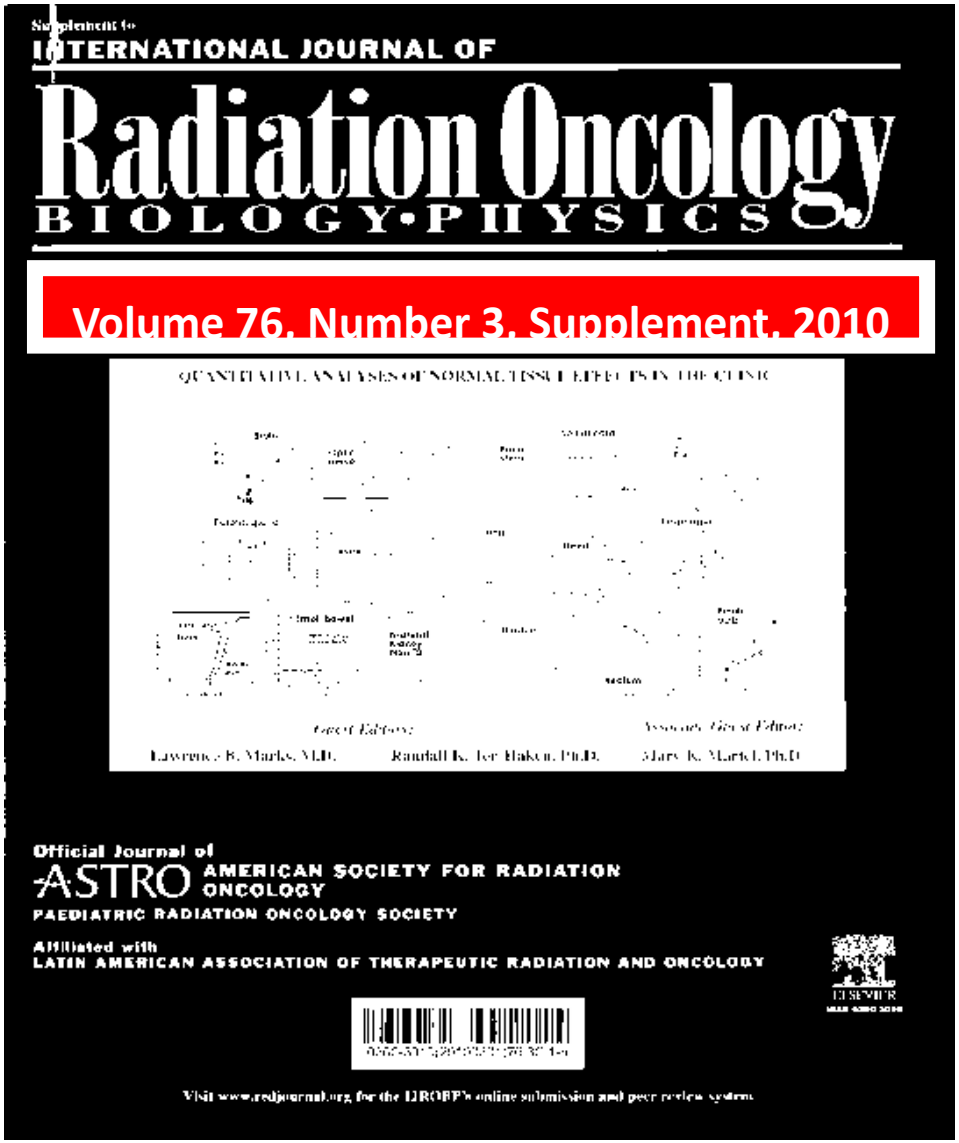
Table 1. Normal tissue tolerance to therapeutic irradiation

Organ	TD 5/5 Volume 1/3	TD 5/5 Volume 2/3	TD 5/5 Volume 3/3	TD 50/5 Volume 1/3	TD 50/5 Volume 2/3	TD 50/5 Volume 3/3	Selected endpoint
Kidney I	5000	3000*	2300	—	4000*	2800	Clinical nephritis
Kidney II							
Bladder	N/A	8000	6500	N/A	8500	8000	Symptomatic bladder contracture and volume loss
Bone:							
Femoral Head I and II	—	—	5200	—	—	6500	Necrosis
T-M joint mandible	6500	6000	6000	7700	7200	7200	Marked limitation of joint function
Rib cage	5000	—	—	6500	—	—	Pathologic fracture
Skin	10 cm² / —	50 cm² / —	100 cm² / 5000	10 cm² / —	30 cm² / —	100 cm² / 6000	Telangiectasia
	7000	6000	5500	—	—	7000	Necrosis Ulceration
Brain	6000	5000	4500	7500	6500	6000	Necrosis Infarction
Brain stem	6000	5300	5000	—	—	6500	Necrosis Infarction
Optic nerve I & II	No partial volume		5000	—	—	6500	Blindness
Chiasma	No partial volume		5000	No partial volume		6500	Blindness
Spinal cord	5 cm / 5000	10 cm / 5000	20 cm / 4500	5 cm / 5000	10 cm / 5000	20 cm / —	Myelitis necrosis
Cauda equina	No volume effect		6000	No volume effect		7500	Clinically apparent nerve damage
Brachial plexus	6200	6100	6000	7700	7600	7500	Clinically apparent nerve damage
Eye lens I and II	No partial volume		1000	—	—	1800	Cataract requiring intervention
Eye retina I and II	No partial volume		4500	—	—	6500	Blindness
Ear mid/external	3000	3000	3000*	4000	4000	4000*	Acute serous otitis
Ear mid/external	5500	5500	5500*	6500	6500	6500*	Chronic serous otitis
Parotid* I and II	—	3200*	3200*	— (TD 100/5 is 5000)	4600*	4600*	Xerostomia
Larynx	7000*	7000*	7000*	9000*	8000*	8000*	Cartilage necrosis
Larynx	—	4500	4500*	—	—	8000*	Laryngeal edema
Lung I	4500	3000	1750	6500	4000	2450	Pneumonitis
Lung II							
Heart	6000	4500	4000	7000	5500	5000	Pericarditis
Esophagus	6000	5800	5500	7200	7000	6800	Clinical stricture/ perforation
Stomach	6000	5500	5000	7000	6700	6500	Ulceration, perforation
Small intestine	5000		4000*	6000		5500	Obstruction perforation/fistula
Colon	5500		4500	6500		5500	Obstruction perforation/ ulceration/fistula
Rectum	Volume 100 cm³ No volume effect		6000	Volume 100 cm³ No volume effect		8000	Severe proctitis/ necrosis/fistula, stenosis
Liver	5000	3500	3000	5500	4500	4000	Liver failure

*<50% of volume doesn't make a significant change.

Organs at Risk: QUANTEC

Quantitative Analysis of Normal Tissue Tolerance in Clinic



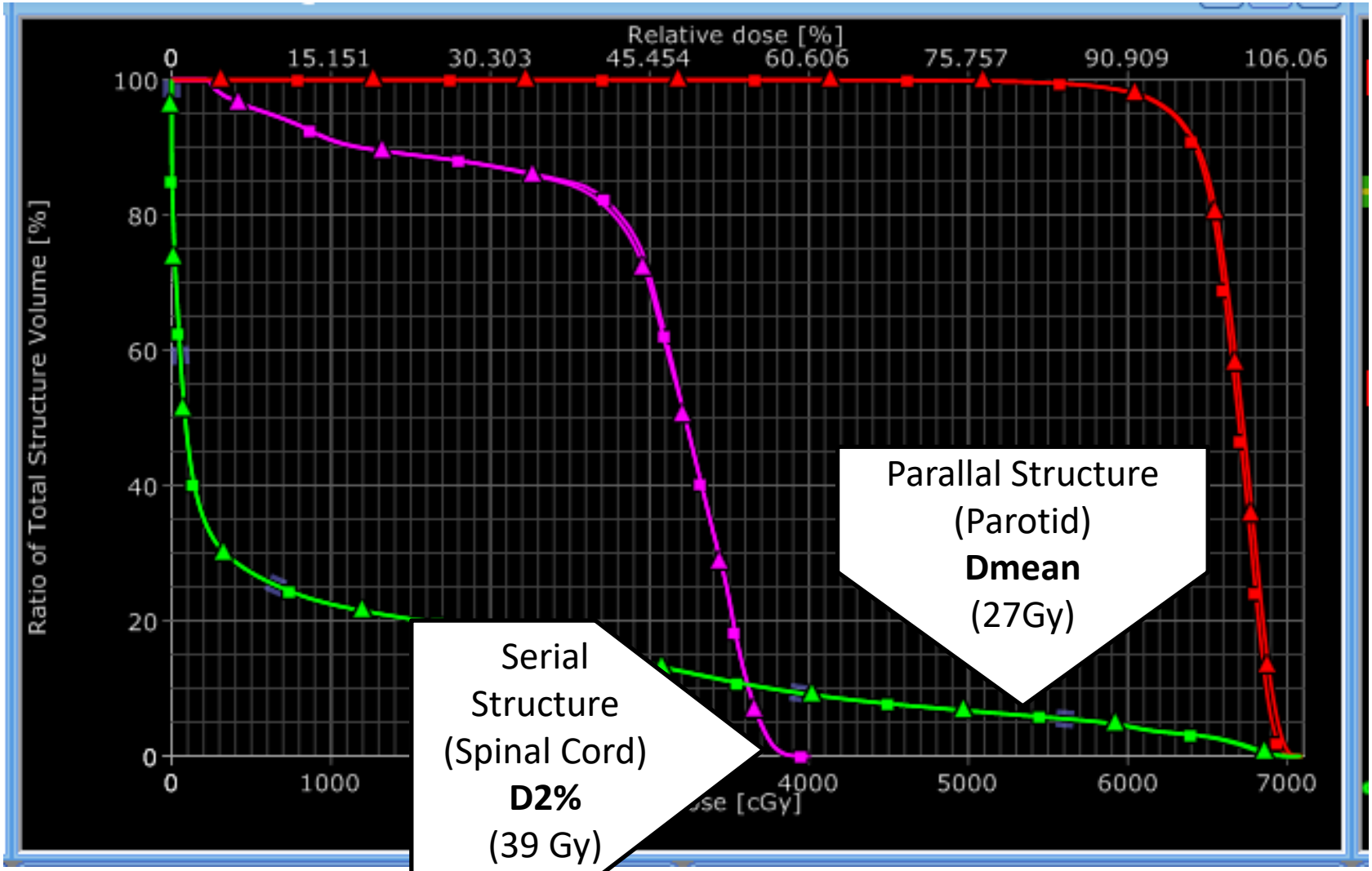
QUANTEC

Organ	Volume segmented	Irradiation type (partial organ unless otherwise stated)†	Endpoint	Dose (Gy), or dose/volume parameters†	Rate (%)	Notes on dose/volume parameters
	Bilateral whole parotid glands	3D-CRT	Long term parotid salivary function reduced to <25% of pre-RT level	Mean dose <39	<50	For combined parotid glands (per Fig. 3 in paper) ¶
Pharynx	Pharyngeal constrictors	Whole organ	Symptomatic dysphagia and aspiration	Mean dose <50	<20	Based on Section B4 in paper
Larynx	Whole organ	3D-CRT	Vocal dysfunction	Dmax <66	<20	With chemotherapy, based on single study (see Section A4.2 in paper)
	Whole organ	3D-CRT	Aspiration	Mean dose <50	<30	With chemotherapy, based on single study (see Fig. 1 in paper)
	Whole organ	3D-CRT	Edema	Mean dose <44	<20	Without chemotherapy, based on single study in patients without larynx cancer**
	Whole organ	3D-CRT	Edema	V50 <27%	<20	
Cochlea	Whole organ	3D-CRT	Sensory neural hearing loss	Mean dose ≤45	<30	Mean dose to cochlear, hearing at 4 kHz
	Whole organ	SRS (single fraction)	Sensory neural hearing loss	Prescription dose ≤14	<25	Serviceable hearing
Parotid	Bilateral whole parotid glands	3D-CRT	Long term parotid salivary function reduced to <25% of pre-RT level	Mean dose <25	<20	For combined parotid glands¶
	Unilateral whole parotid gland	3D-CRT	Long term parotid salivary function reduced to <25% of pre-RT level	Mean dose <20	<20	For single parotid gland. At least one parotid gland spared to <20 Gy¶

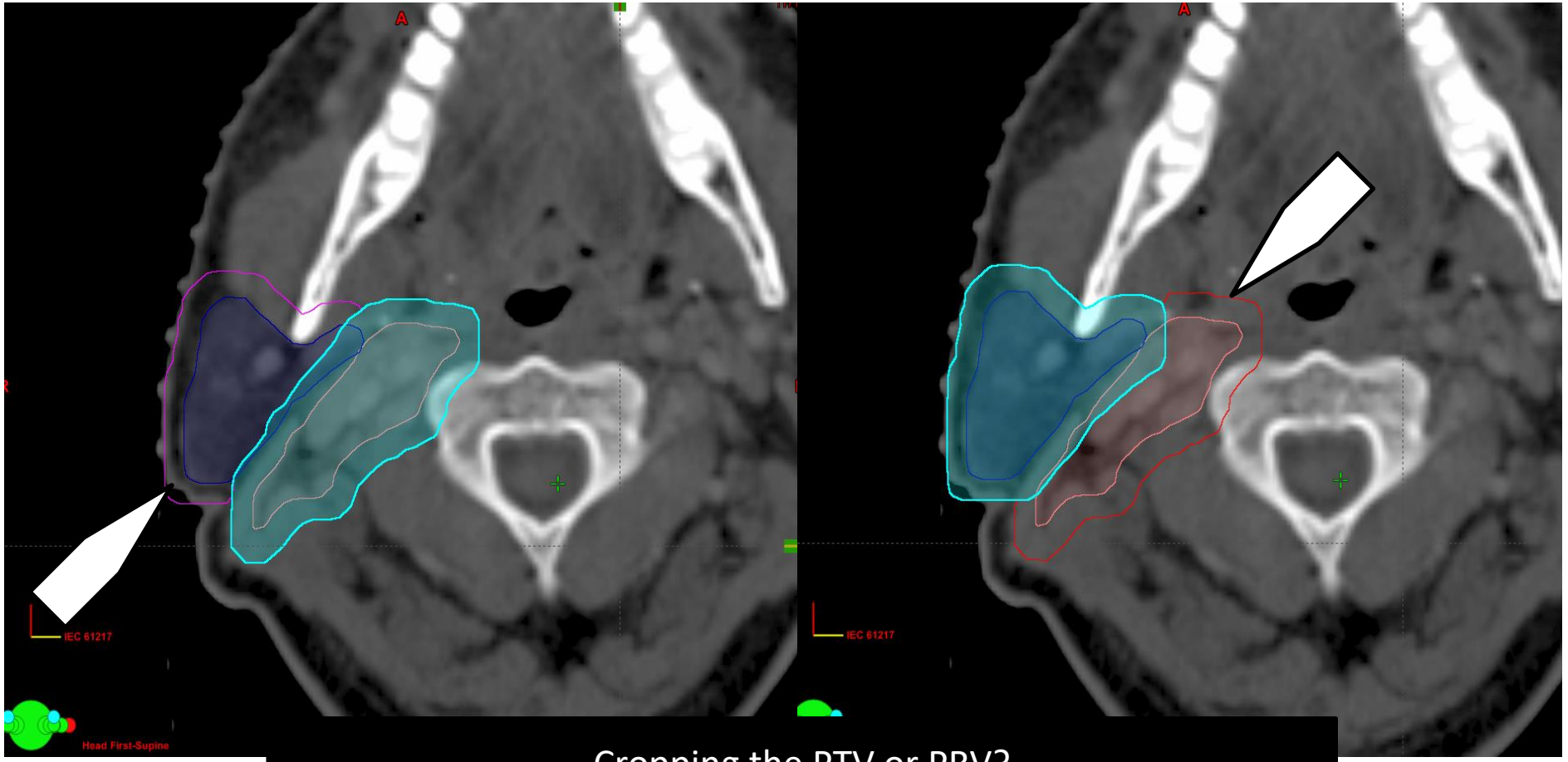
QUANTEC

Organ	Volume segmented	Irradiation type (partial organ unless otherwise stated)†	Endpoint	Dose (Gy), or dose/volume parameters†	Rate (%)	Notes on dose/volume parameters
Brain	Whole organ	3D-CRT	Symptomatic necrosis	Dmax <60	<3	Data at 72 and 90 Gy, extrapolated from BED models
	Whole organ	3D-CRT	Symptomatic necrosis	Dmax = 72	5	
	Whole organ	3D-CRT	Symptomatic necrosis	Dmax = 90	10	
	Whole organ	SRS (single fraction)	Symptomatic necrosis	V12 <5–10 cc	<20	Rapid rise when V12 > 5–10 cc
Brain stem	Whole organ	Whole organ	Permanent cranial neuropathy or necrosis	Dmax <54	<5	
	Whole organ	3D-CRT	Permanent cranial neuropathy or necrosis	D1–10 cc‖ ≤59	<5	
	Whole organ	3D-CRT	Permanent cranial neuropathy or necrosis	Dmax <64	<5	Point dose <<1 cc
	Whole organ	SRS (single fraction)	Permanent cranial neuropathy or necrosis	Dmax <12.5	<5	For patients with acoustic tumors
Optic nerve / chiasm	Whole organ	3D-CRT	Optic neuropathy	Dmax <55	<3	Given the small size, 3D CRT is often whole organ‡‡
	Whole organ	3D-CRT	Optic neuropathy	Dmax 55–60	3–7	
	Whole organ	3D-CRT	Optic neuropathy	Dmax >60	>7-20	
	Whole organ	SRS (single fraction)	Optic neuropathy	Dmax <12	<10	
Spinal cord	Partial organ	3D-CRT	Myelopathy	Dmax = 50	0.2	Including full cord cross-section
	Partial organ	3D-CRT	Myelopathy	Dmax = 60	6	
	Partial organ	3D-CRT	Myelopathy	Dmax = 69	50	
	Partial organ	SRS (single fraction)	Myelopathy	Dmax = 13	1	Partial cord cross-section irradiated
	Partial organ	SRS (hypofraction)	Myelopathy	Dmax = 20	1	3 fractions, partial cord cross-section irradiated

DVH of OAR (PRV)

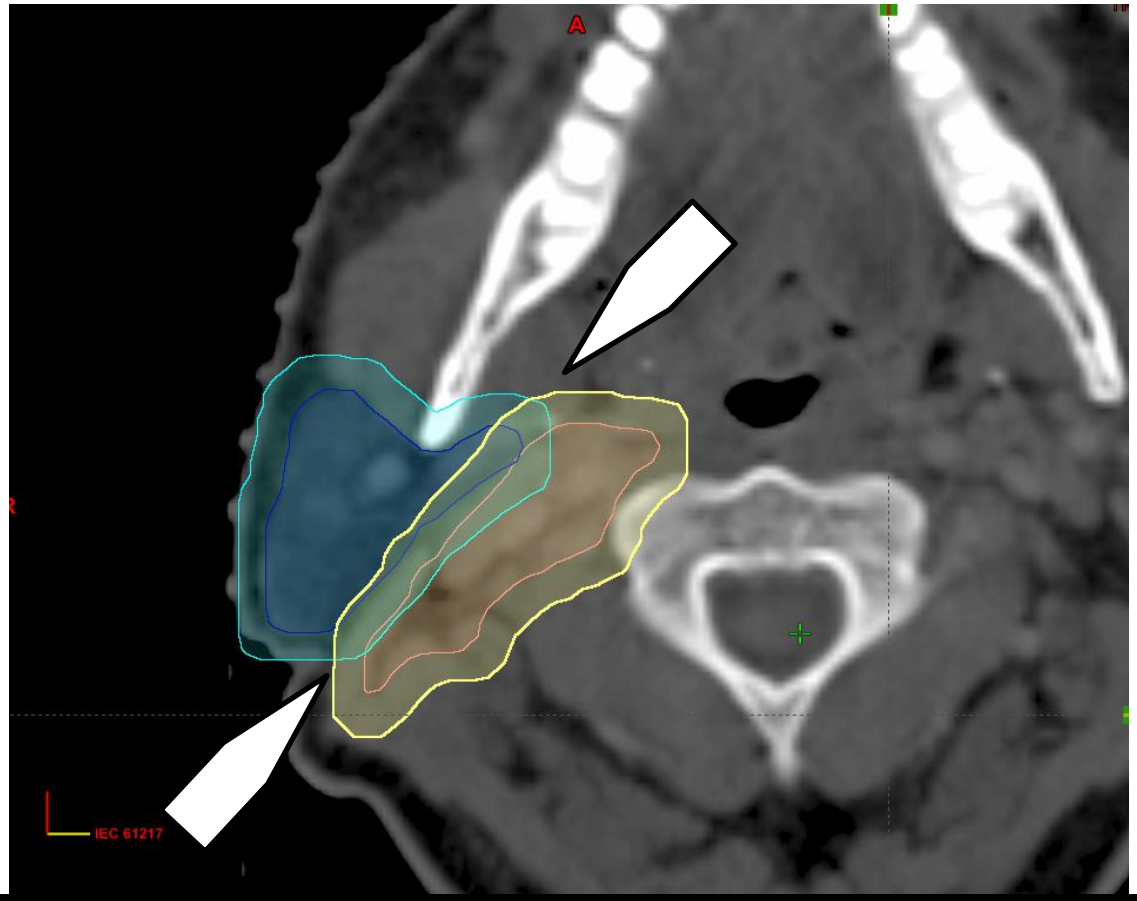


Overlapping CTV & OAR



Cropping the PTV or PRV?

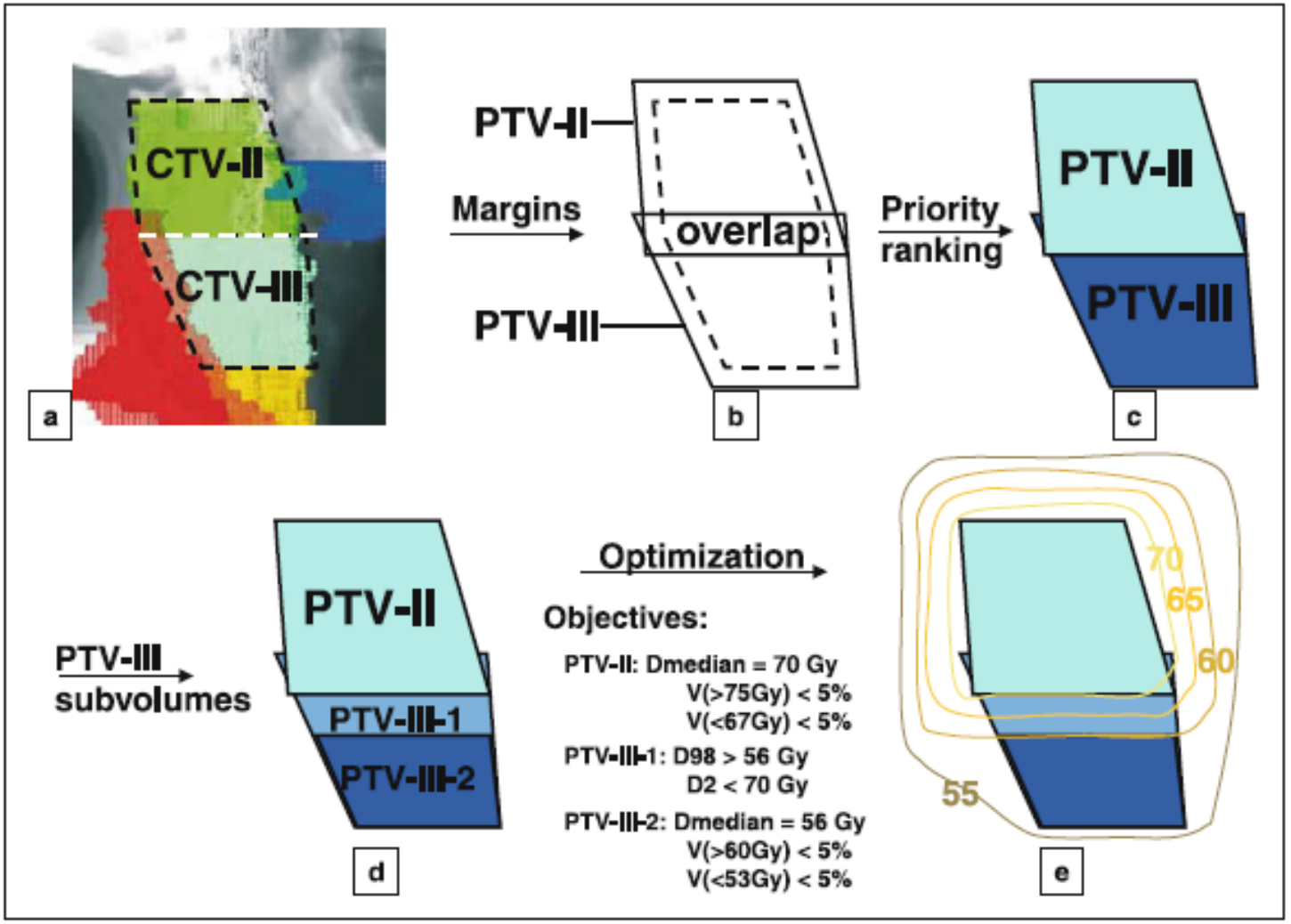
No Cropping!



Planning constraints and priorities to be adjusted for desirable dose

Practical IMRT Planning

Wilfried De Neve, Yan Wu, Gary Ezzell

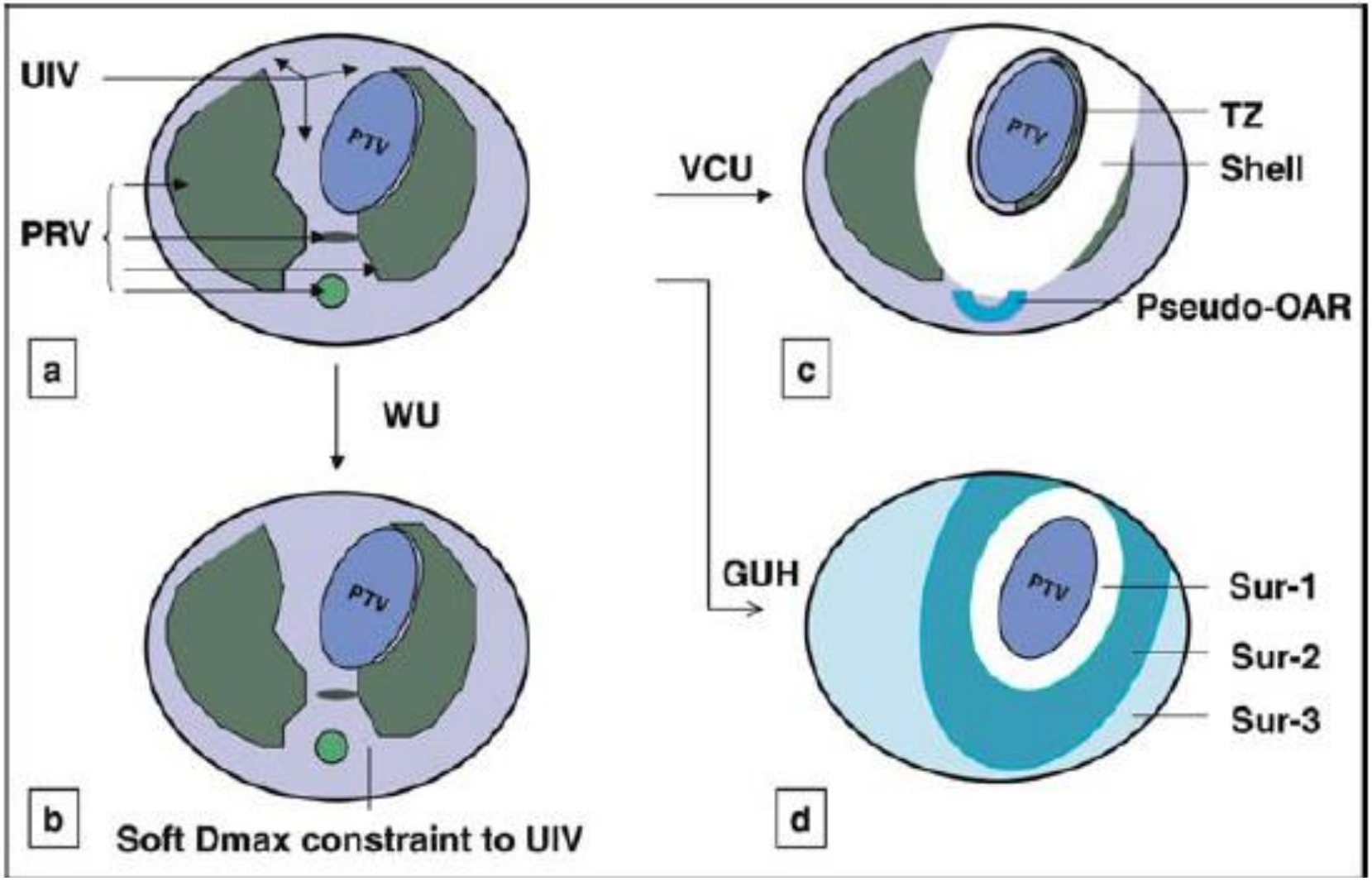


Planning for overlaps in PTVs or PTV / OAR

Solutions for overlap

1. Assigning a much higher importance weight to PTV-II than to PTV-III at optimization;
2. Relaxing the maximum dose objective for PTV-III;
3. Fragmentation of the PTV-III volume (panel d) and relaxing the maximum dose objective for a subvolume of PTV-III or a combination of 1–3
4. Fragmentation of PTV-III to create a subvolume for relaxing the maximum dose constraint;
5. Unambiguous dose objectives for plan optimization

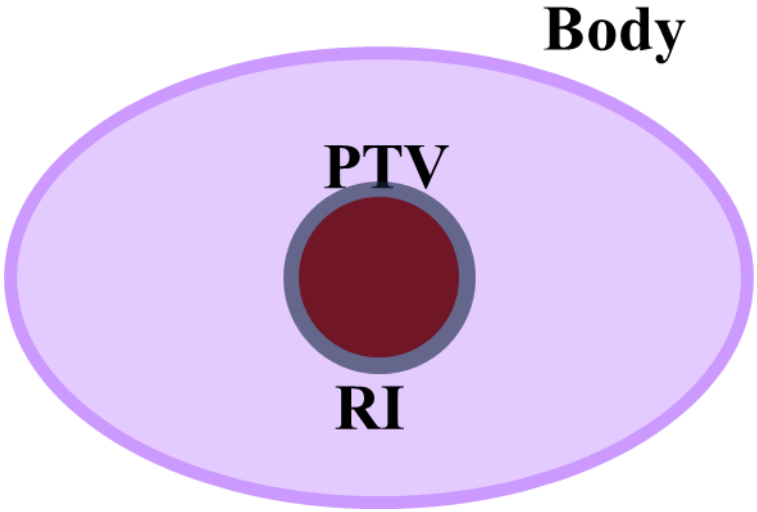
Checking for dose littering



Solutions for dose littering

1. volume containing a PTV, 4 PRV and the remaining of the imaged volume called UIV: Unspecified Imaged Volume;
2. method described by investigators from Washington University. A soft Dmax (dose maximum) constraint is assigned the whole UIV;
3. method used at Virginia Commonwealth University. No constraints imposed to a narrow TZ (transitional zone) immediately outside PTV but to a shell surrounding the TZ. Inside the remaining UIV, one or more Pseudo-OAR(s) are constructed or draw an RVR.
4. “Matroska” method described by investigators from Ghent University Hospital. Several shell structures inside each other (like Russian matroskas) leave no UIV. Outer shells have more severe dose maximum constraints than inner shells.

Perfectly conformal plan…

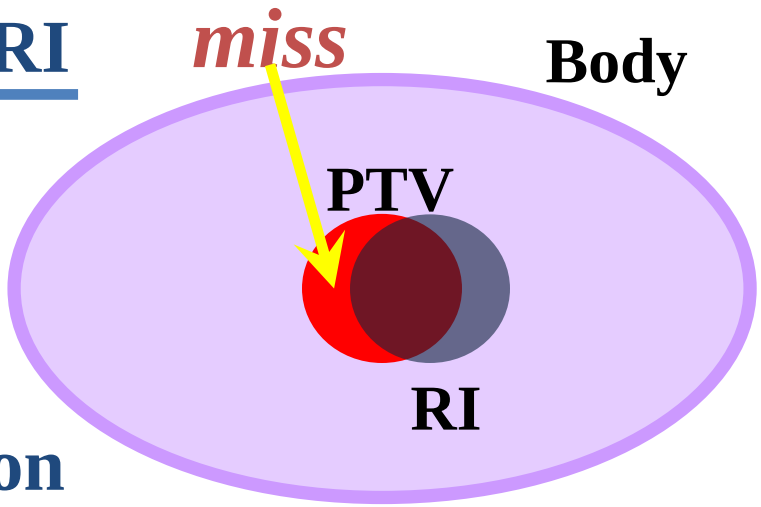


- how much of PTV is covered?
- how much is the spill?
- how is the uniformity within PTV?

Coverage Factor

- ***tells you how much you <u>miss</u> on PTV***

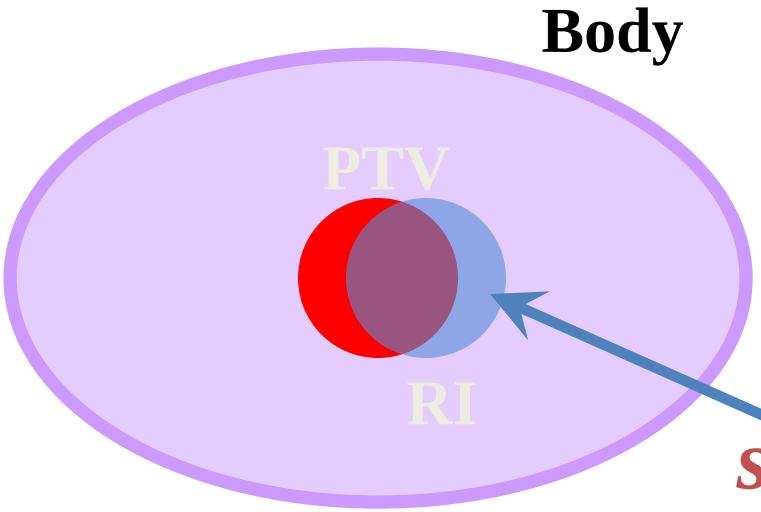
$$\frac{\text{volume of PTV covered by RI}}{\text{volume of PTV}}$$



$$\frac{\text{volume of overlapping region}}{\text{volume of PTV}}$$

ideal value = 1

Conformity Index *(CI)*



tells you how much you <u>spill</u> outside PTV

- ratio of 
- ratio of 
- ideally = 1; but expect around 1.3 to 1.5
- presently, inverse of the ratio is followed

Conformity Index ICRU 50

- Conformity Index (CI) = TV/PTV
- TV = treated volume is the tissue volume that receives at least the dose selected and specified
- CI => optimised close to 1.0
- For small volumes CI up to 2 can be acceptable (SRS)
- For bigger volumes, CI should be closer to 1

Homogeneity Index *(HI)*

- measure of uniformity within PTV

- expressed as the ratio D_2/D_{98}
  - **D_2** is the maximum dose received by **at least 2% of the PTV**
  - **D_{98}** is the maximum dose received by **at least 98% of the PTV**

Homogeneity Index (RTOG-1993)

$$HI_{RTOG} = I_{max}/RI$$

(I_{max} = maximum isodose in the target, RI reference isodose)

Ideal HI $\leq$ 2

Minor violation = 2 to 2.5

Major violation > 2.5 (Clinical discretion needed)

Alternative formula

$$HI = D_2 - D_{98}/DP \times 100$$

(D_2 =minimum dose to 2 % of the target

D_{98} = minimum dose to 98% of the target

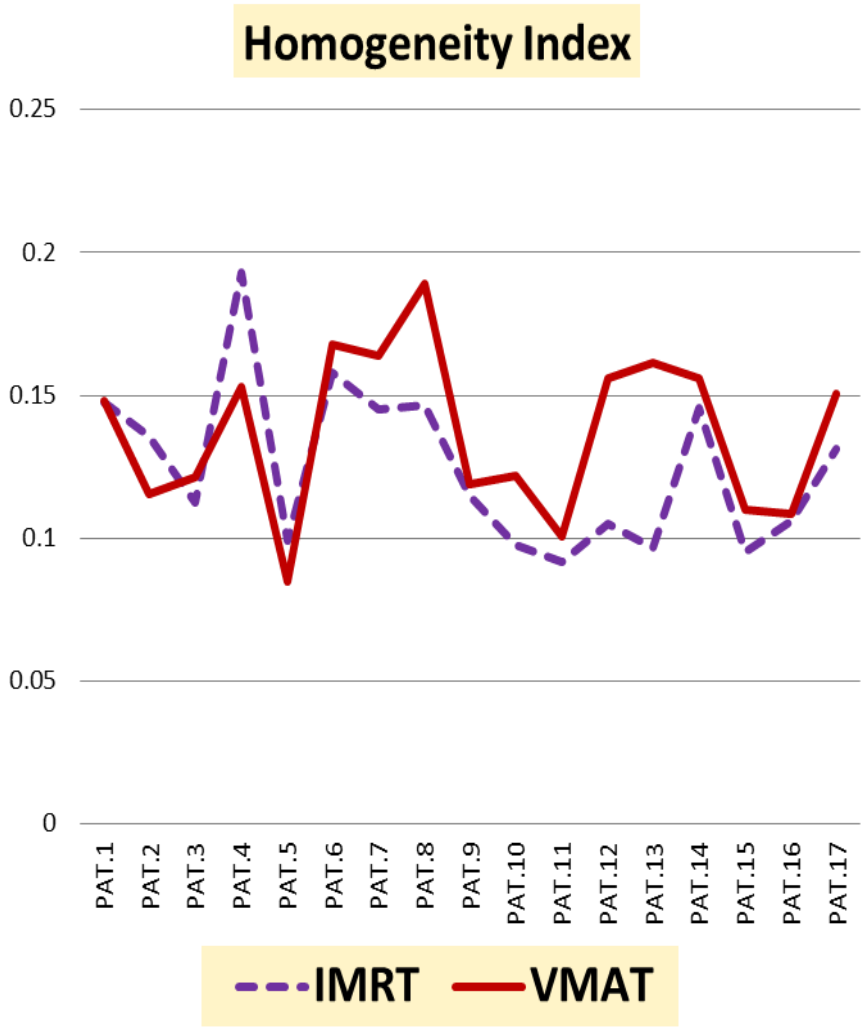
D_P = prescribed dose)

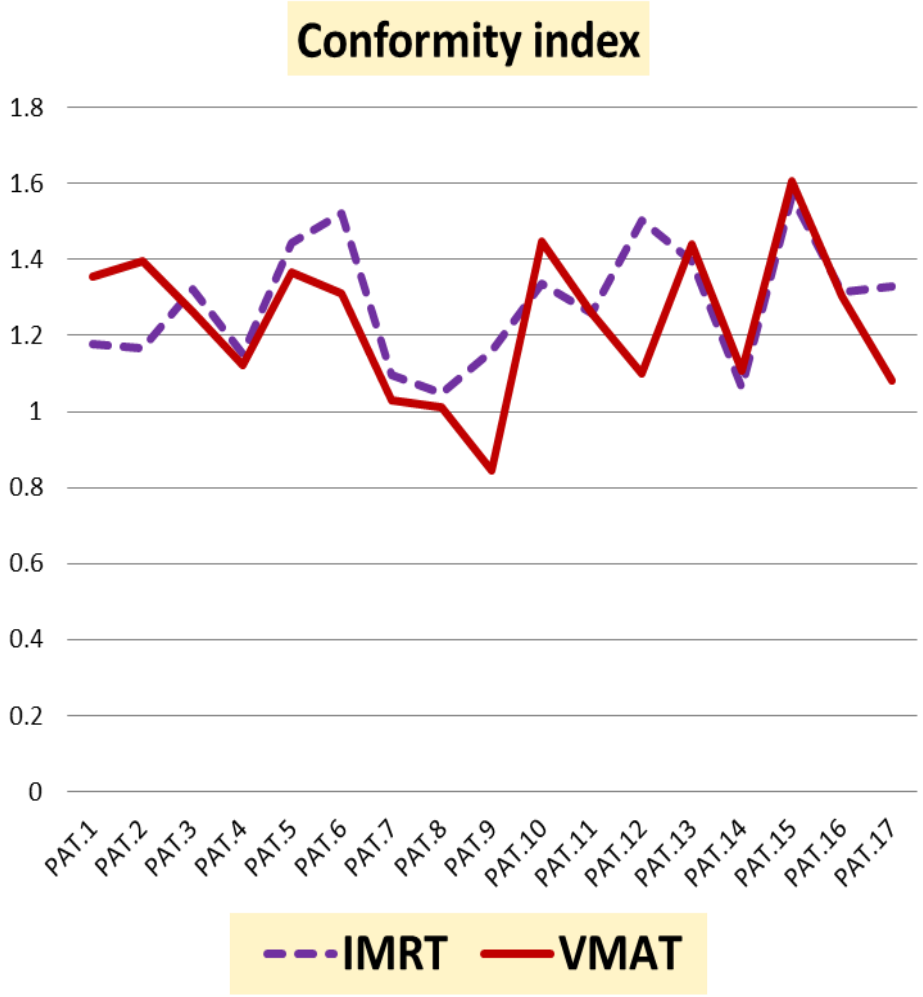
Homogeneity Index *(HI)*

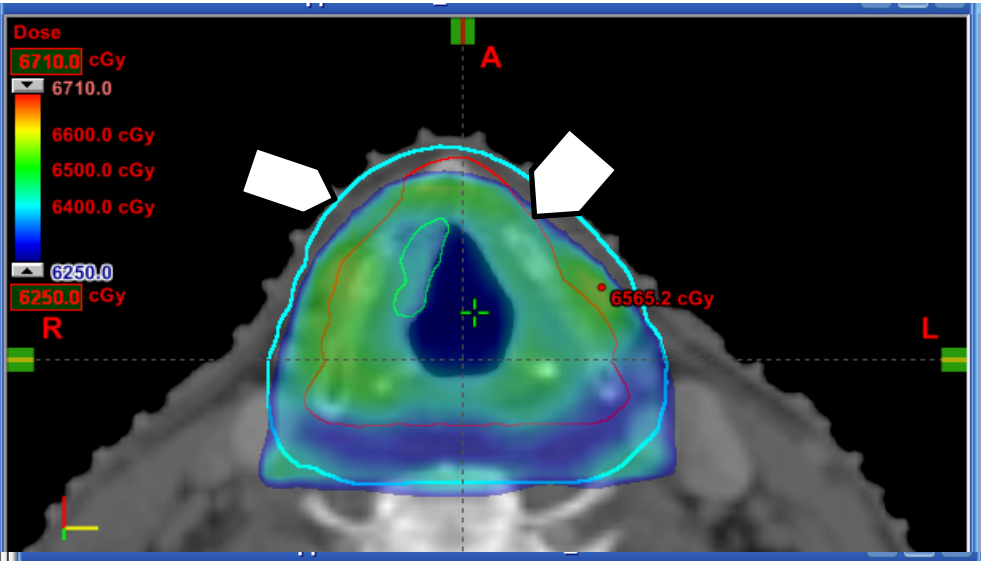
- for a typical 3-D CRT plan, it is around 1.07
- for IMRT it should be ≤ 1.15

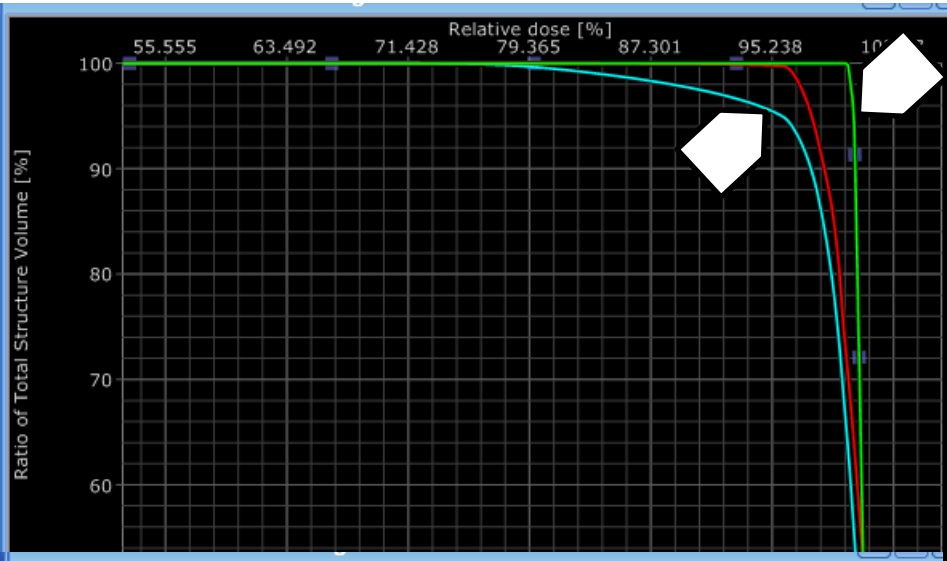
- D_5 / D_{95} has also been used

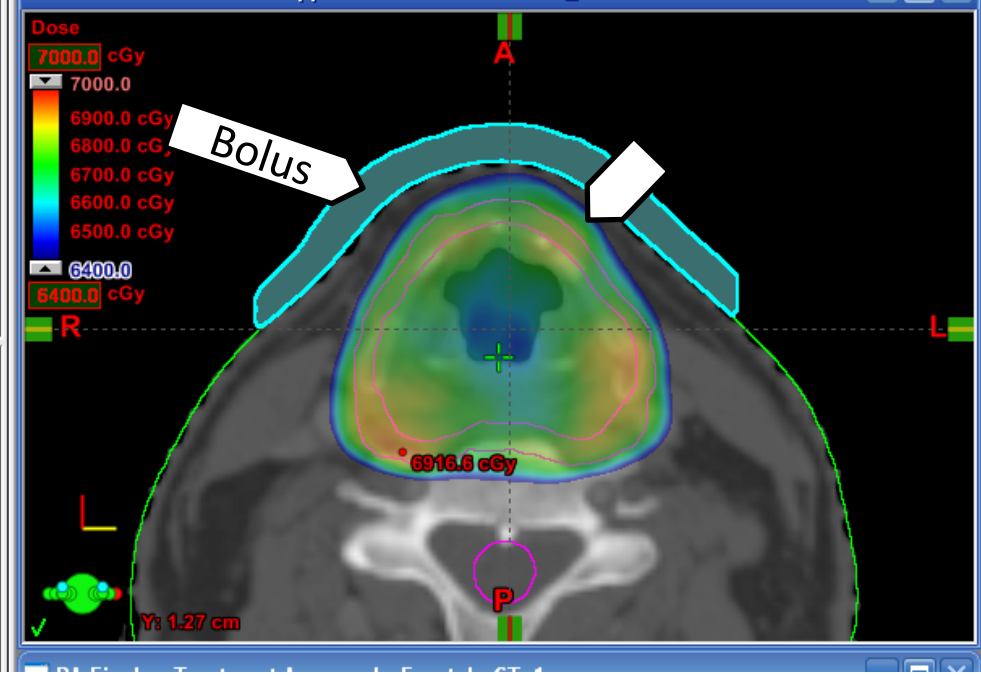
Conformity & Homogeneity indices

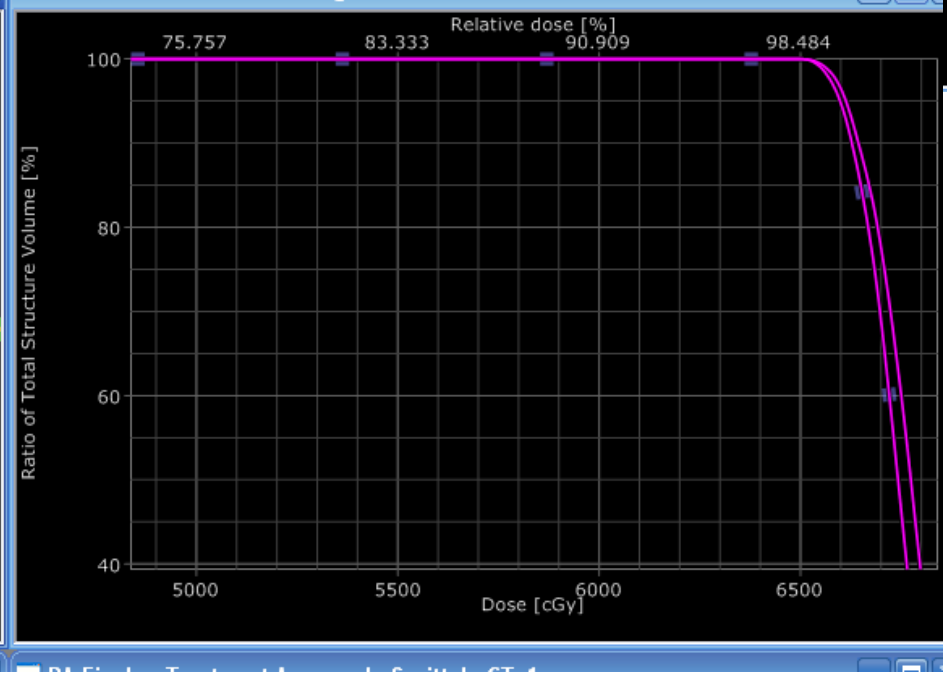




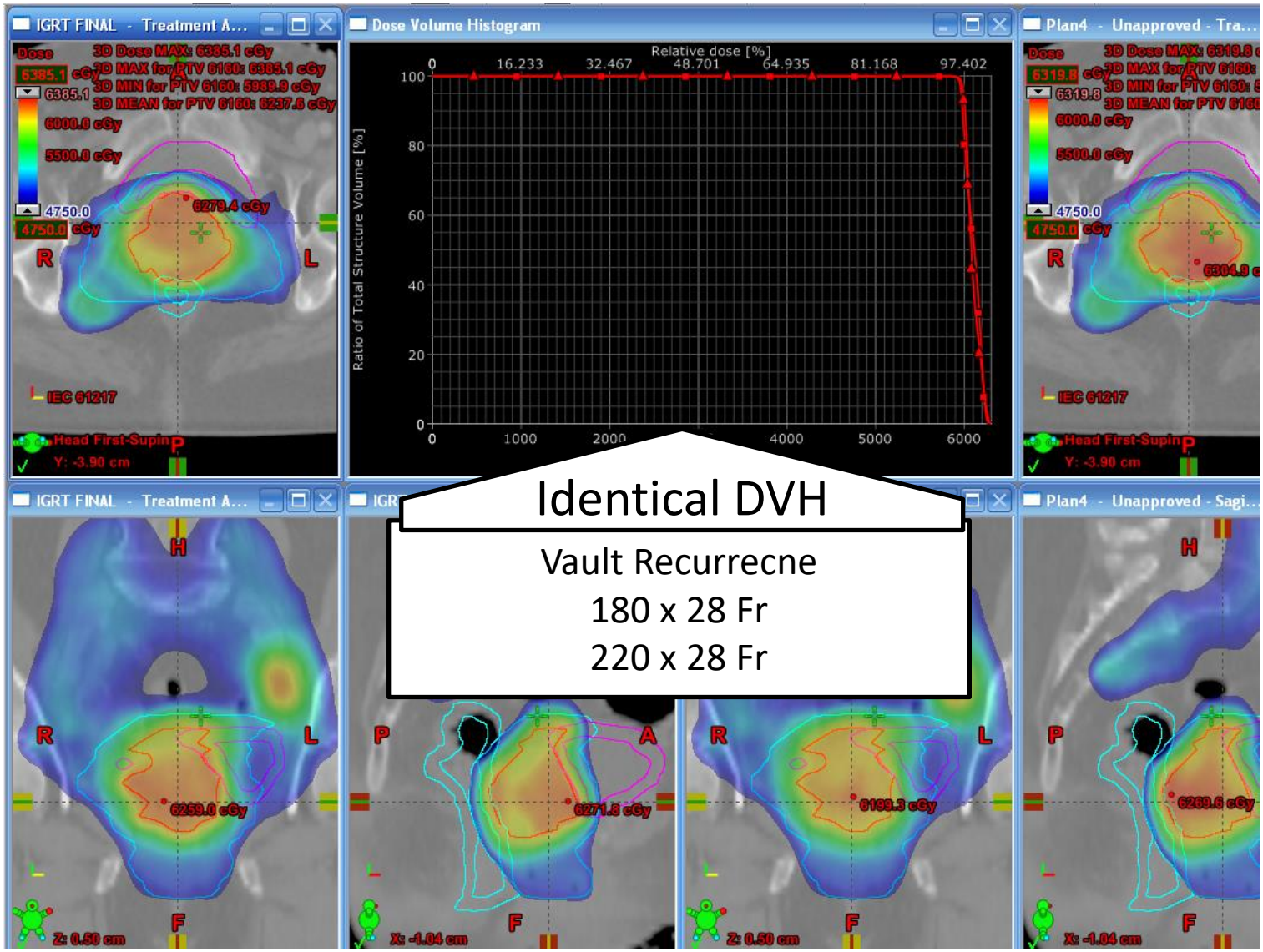

Dose
6710.0 cGy
6710.0
6600.0 cGy
6500.0 cGy
6400.0 cGy
6250.0
6250.0 cGy
A
R
L
6565.2 cGy


Relative dose [%]
55.555
63.492
71.428
79.365
87.301
95.238
100
90
80
70
60
Ratio of Total Structure Volume [%]

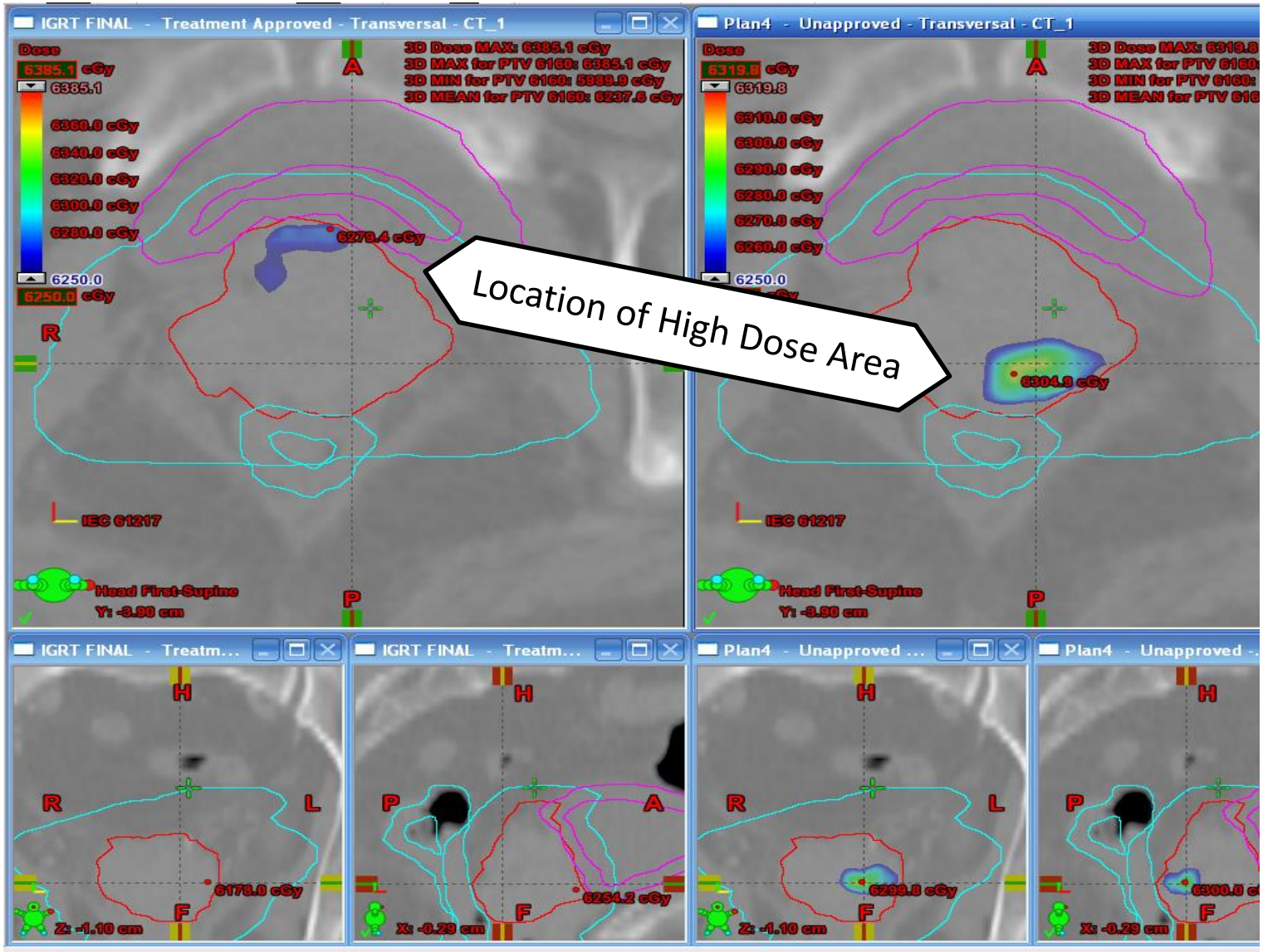

Dose
7000.0 cGy
7000.0
6900.0 cGy
6800.0 cG
6700.0 cGy
6600.0 cGy
6500.0 cGy
6400.0
6400.0 cGy
A
R
L
P
Bolus
6916.6 cGy
Y: 1.27 cm


Relative dose [%]
75.757
83.333
90.909
98.484
100
80
60
40
Ratio of Total Structure Volume [%]
5000
5500
6000
6500
Dose [cGy]

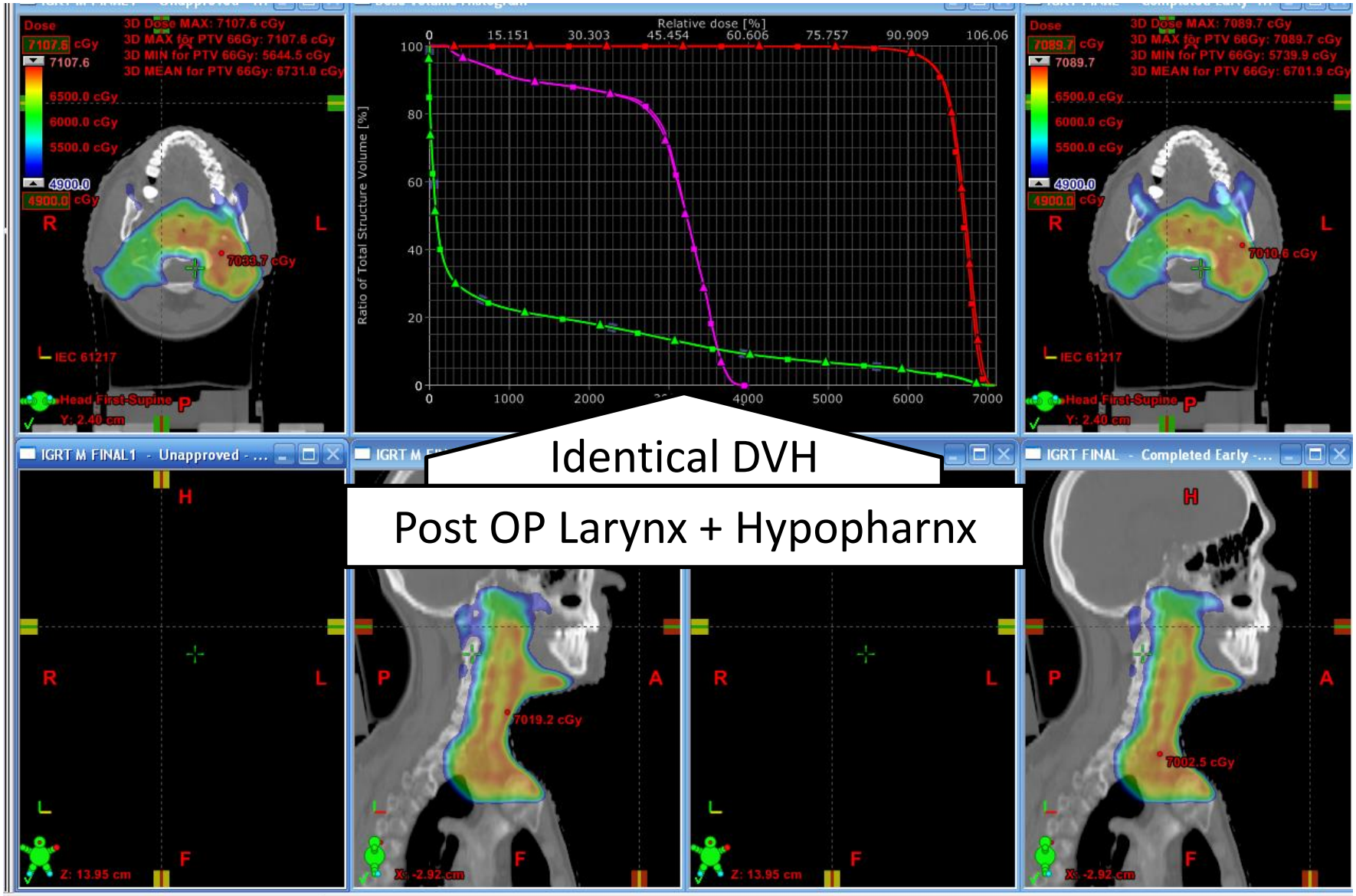
What the DVH doesn't tell



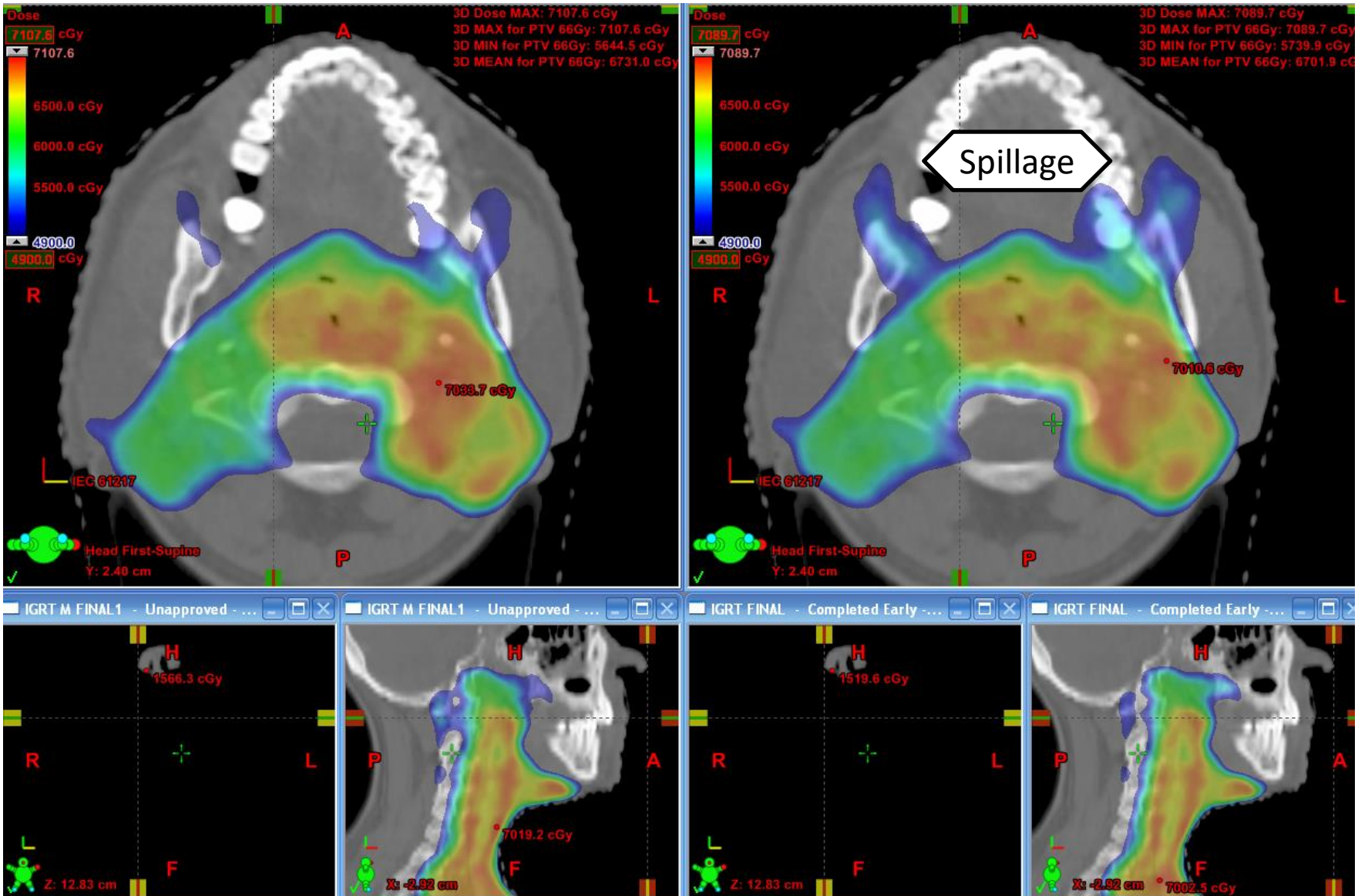
What the DVH doesn't tell



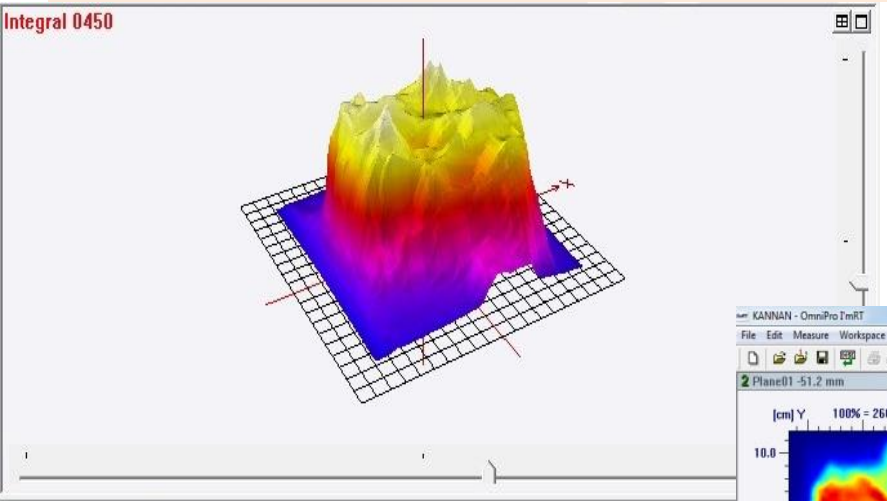
What the DVH doesn't tell

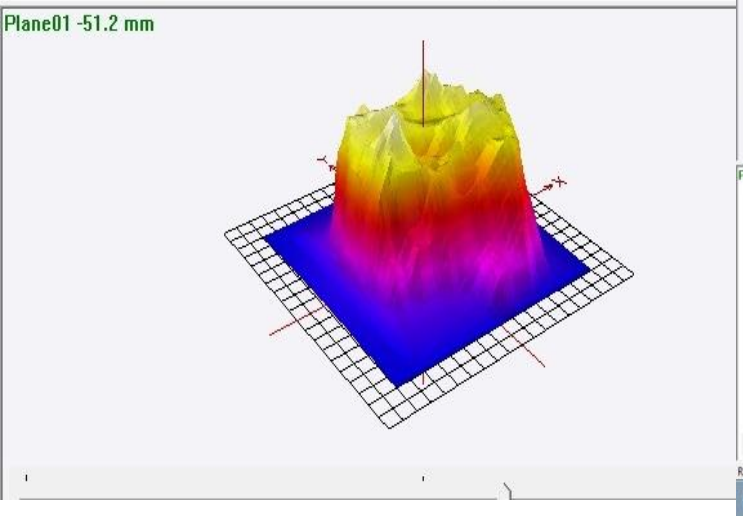


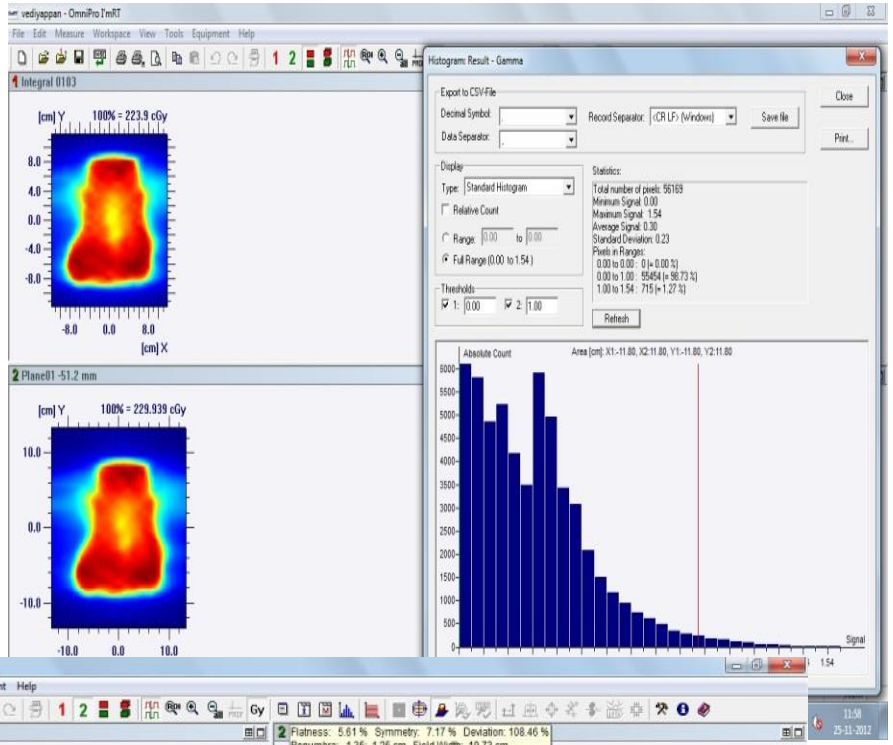
What the DVH doesn't tell

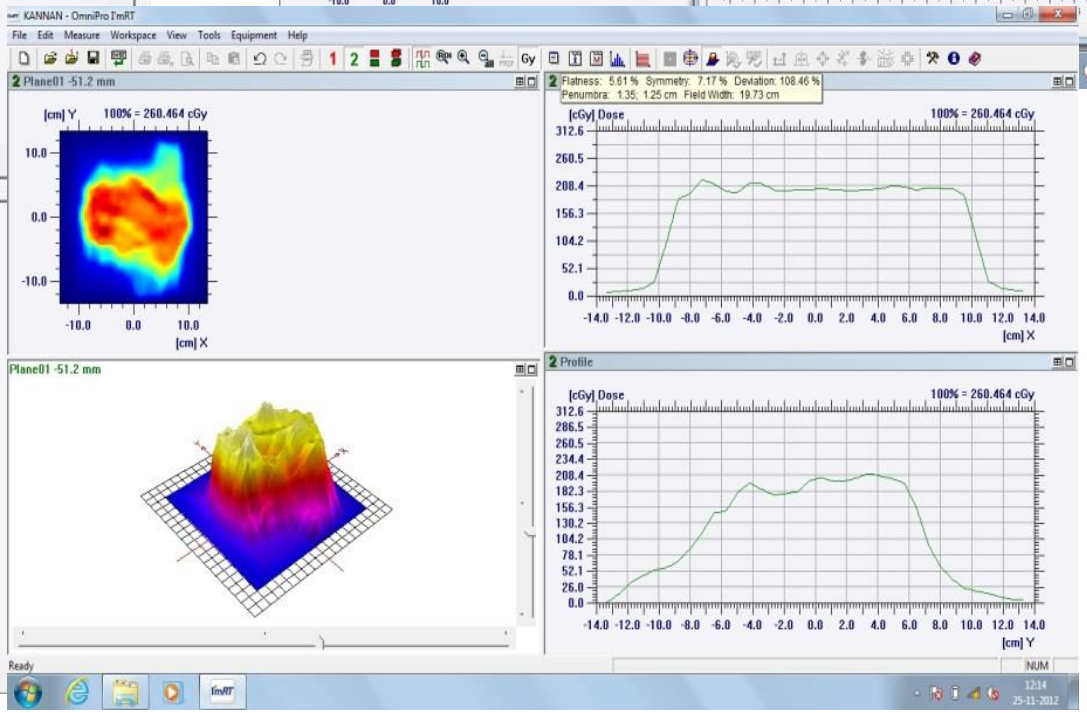


QA…… Fluence analyses showed most planned cases treatable with ≥ 95% fidelity









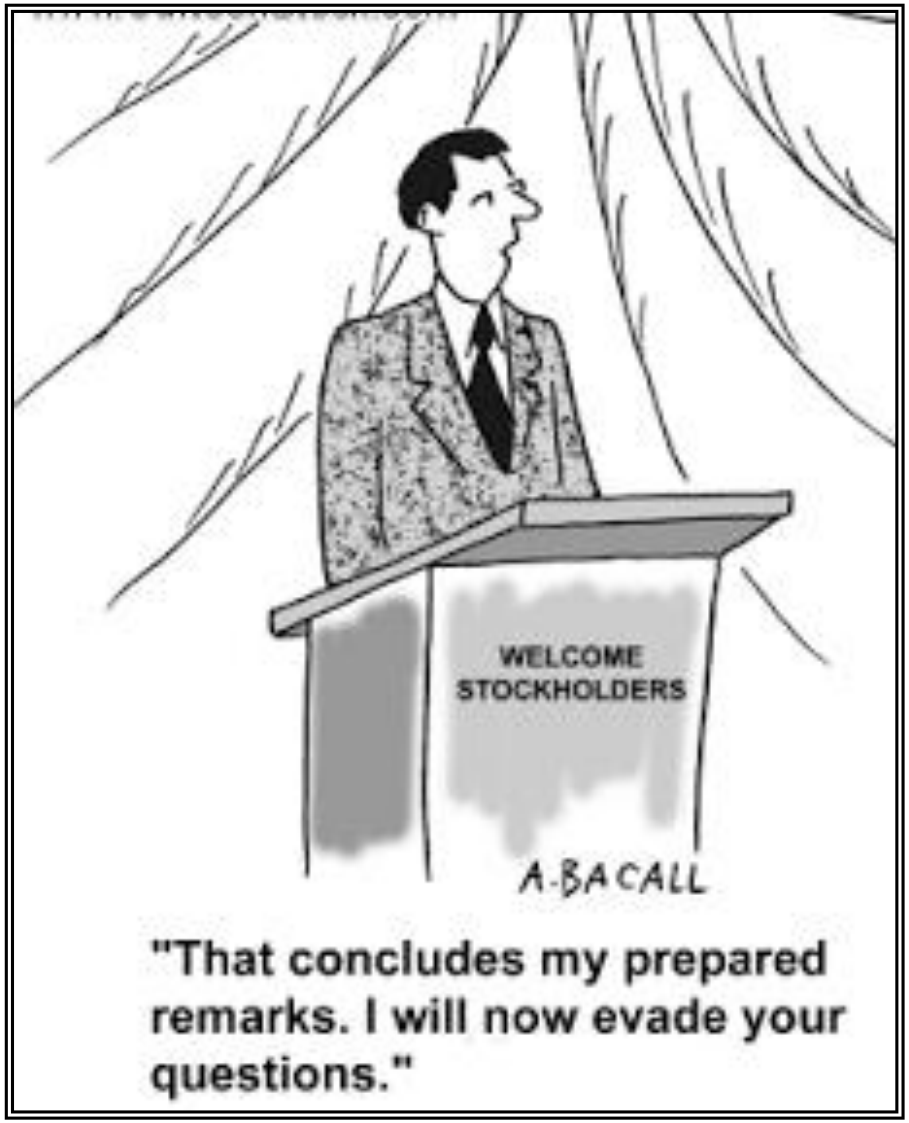
Learning for the day

- Definitions of new volumes as per ICRU 83
- 2D to 3D to IMRT planning
- Evaluation of dose at a relevant point
- Evaluation of dose as a volume
- Accounting for inhomogeneity
- Accounting for overlapping volumes

Learning for the day

- Mathematical and graphical representation of dose across a volume
- No more hot spots & cold spots
- D_2, D_{98} and D_{mean} are the new standards
- Conformity & Homogeneity indices
- Limitation of DVH
- Ability to choose a proper radiation plan on the basis of these variables

Thank You


WELCOME
STOCKHOLDERS
A-BACALL
"That concludes my prepared remarks. I will now evade your questions."