Treatment Planning Skills That a Physicist Should Know

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61ST ANNUAL MEETING & EXHIBITION | SAN ANTONIO, TX

BUILDING BRIDGES. CULTIVATING SAFETY. GROWING VALUE.

Conflict of Interest

- Nothing to disclose

Learning Objective

- To familiarize with a variety of modern photon beam radiotherapy techniques
- To understand the workflow for treatment planning and factors affecting plan quality
- Conventional radiotherapy requires to achieve a uniform dose distribution inside the target volume and a dose as low as possible in the healthy tissues surrounding the target
- SBRT is becoming a standard for radiotherapy and RTOG protocols for SBRT treatment planning
- SRS/SRT planning and associated RTOG Guidelines


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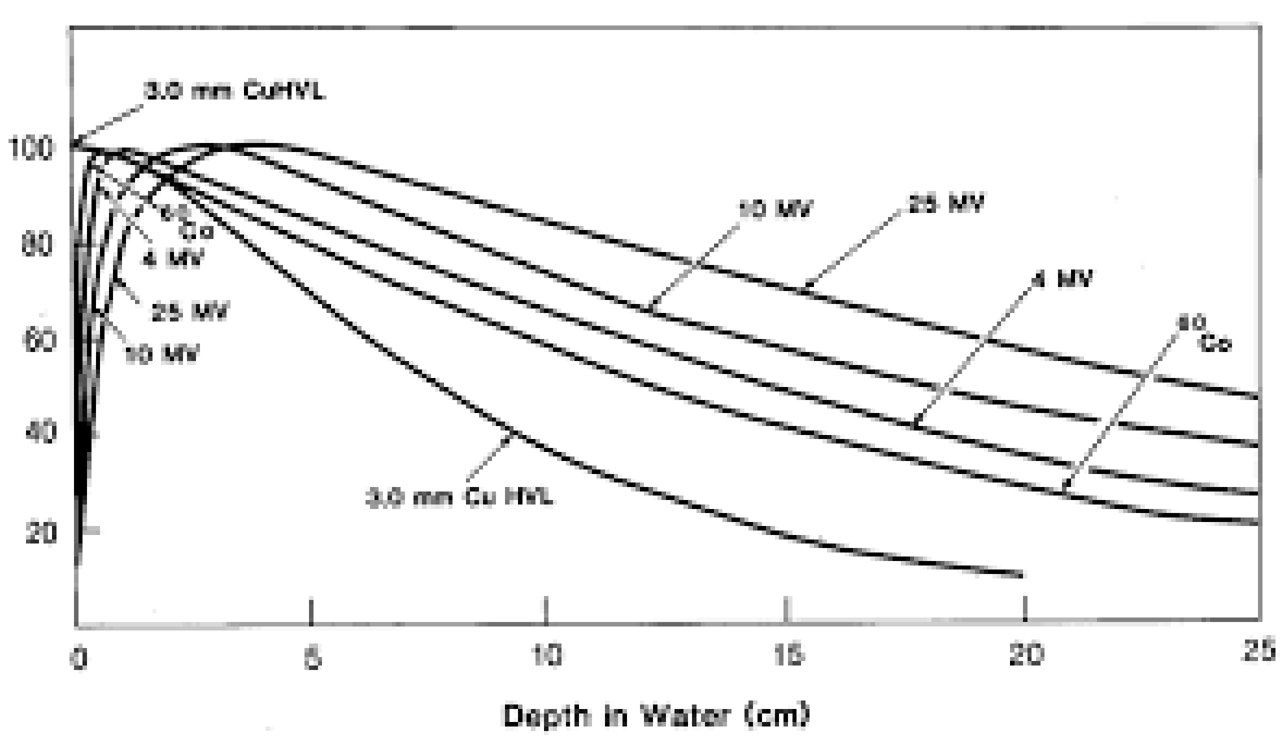
PLANNING AND TREATMENT
Arthur J. Olch, Ph.D., FAAPM
CRC Press

Treatment Planning Resource

- Workshop
- Training Courses
- Colleagues/coworkers
- Some websites: econtour.com, prowork.com, etc.

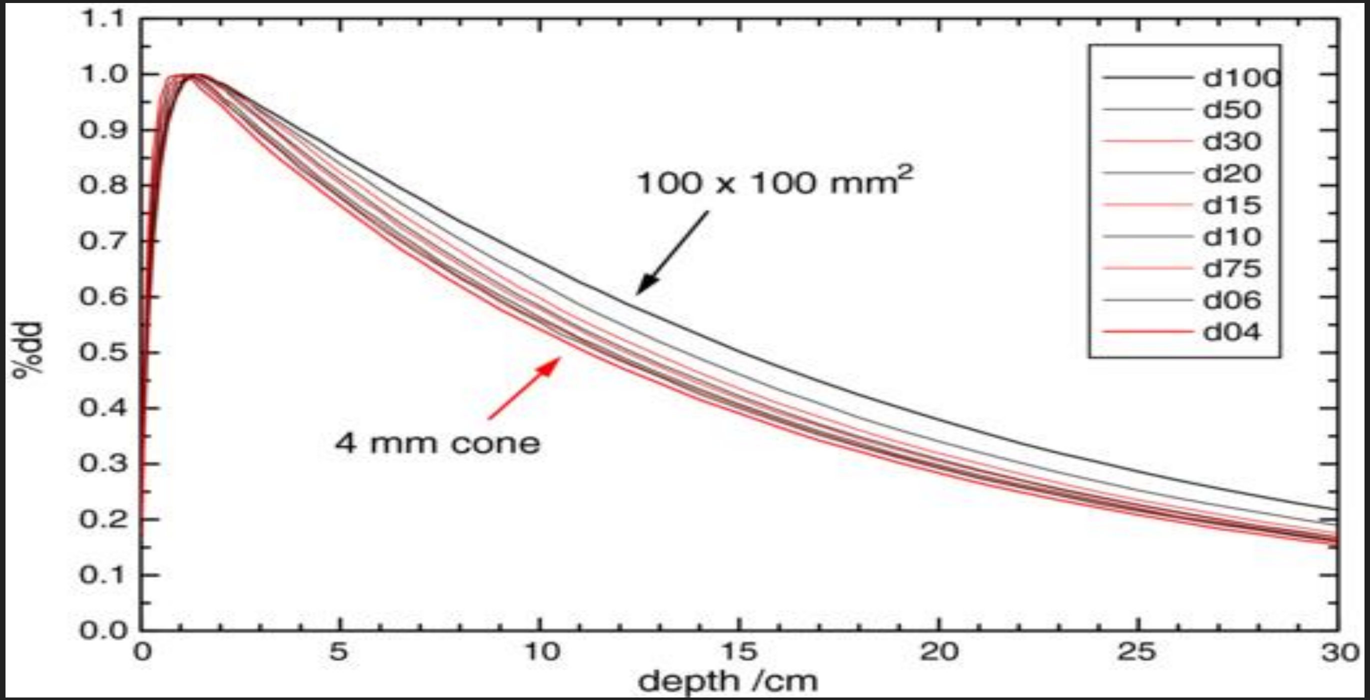
Photon Beam Characteristics

- PDD vs Energy



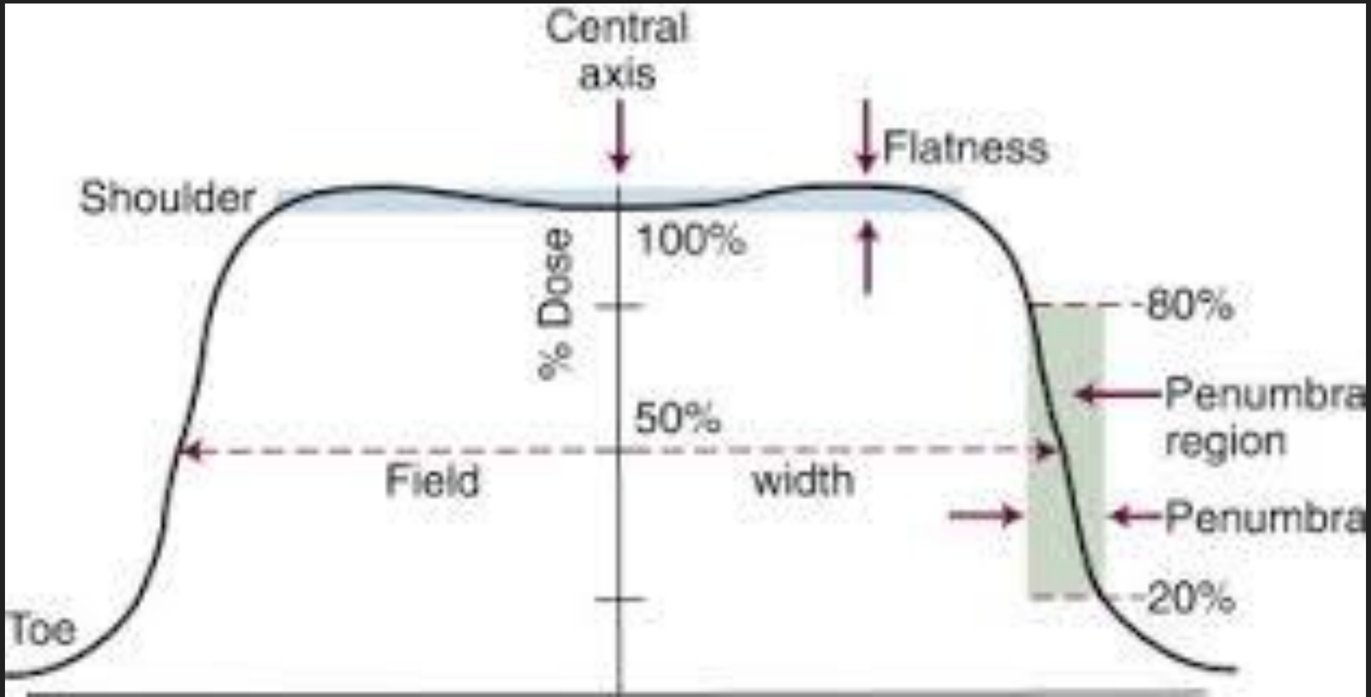
Photon Beam Characteristics

- PDD vs Field Size
  - George X Ding and Rob Krauss, Published 20 June 2013 • 2013 Institute of Physics and Engineering in Medicine Physics in Medicine & Biology, Volume 58, Number 14)

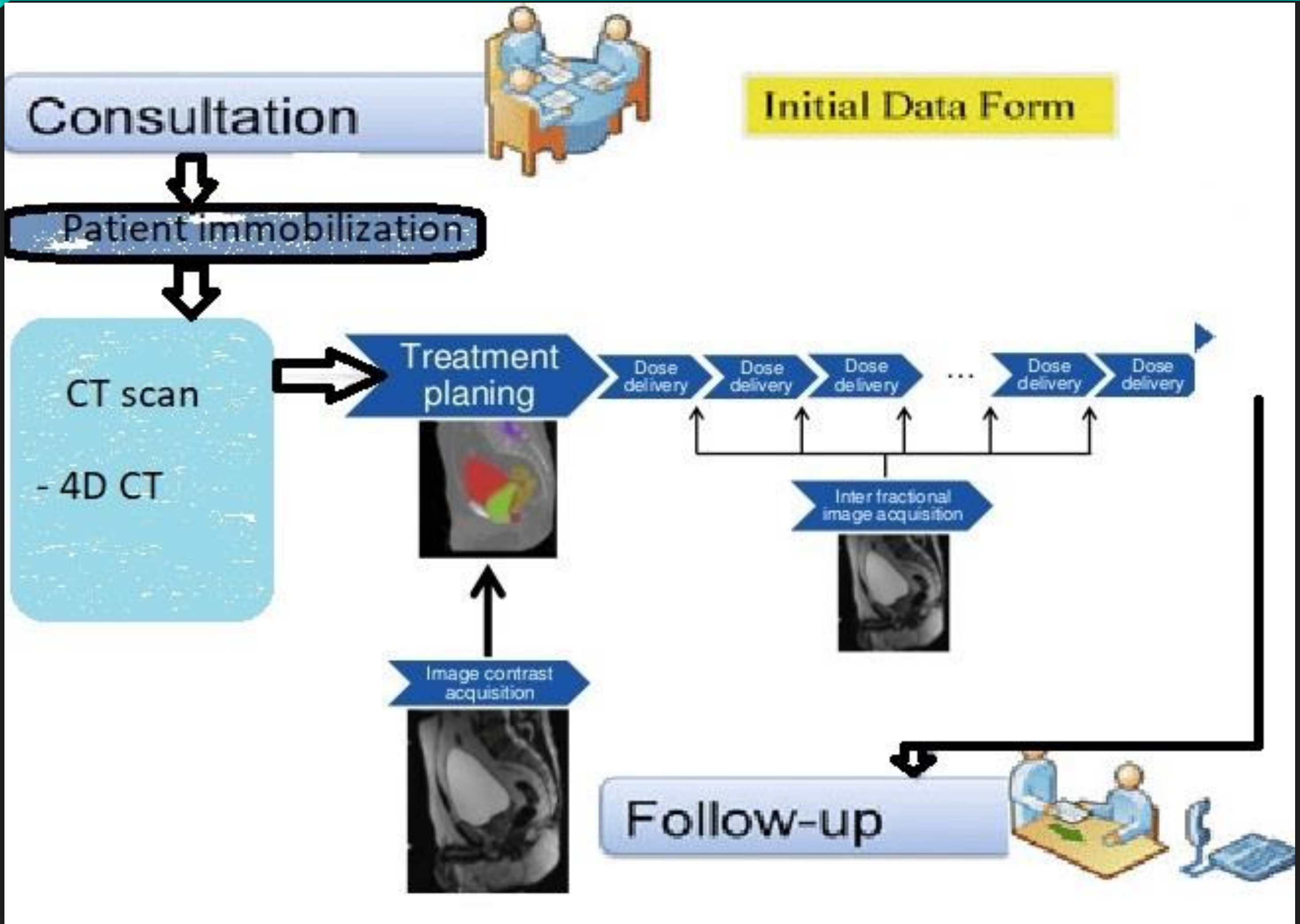


Photon Beam Characteristics

- Profile vs Field Size
  - Single beam penumbra ~ 7-8 mm, from 80%- 20% ➔ iso-dose lines ~ 10%/mm
  - VMAT/IMRT isodose lines are subjected to this radiation physics
  - Multiple beams make the beam penumbra shallower



Radiation Oncology Workflow



Treatment Planning

- Prescription:
  - Convention vs SRS/SBRT
  - Patient specific planning requirements
  - What to compromise if you can not achieve planning requirements
  - Uniform dose in PTV important?
  - Surrounding structure sparing more important than PTV coverage?
  - What is Rx dose and daily fractional dose?

What do we need in planning stage?

- Target and critical structure delineation
  1. Anatomy:
     - Scout image
     - Dynamic scanning
     - Gated acquisition

     i. Functional information, e.g. important brain areas, functional lung, bioimaging for tumor

     ii. Registration methods; data communication; new image modalities
     – multimodality imaging; registration
  2. RTOG target and OARs atlas for different sites

Breast Cancer

- RTOG target and OARs atlas for breast cancer
  - Breast CTV
  - PTV=CTV+5mm
  - Lumpectomy GTV
  - Chestwall CTV
  - Regional nodal volumes
  - Ipsilateral lung, heart, and contralateral breast

RTOG. Breast cancer atlas for radiation therapy planning: consensus definitions. 2018 [Available from: http://www.rtog.org/LinkClick.aspx?fileticket=vzJFhPaBipE%3d&tabid=236.

Breast Cancer

- Many studies show that toxicities were associated with dose inhomogeneity
  - Both acute and long term toxicities such as moist desquamation, pain, breast discomfort and breast hardness
- Randomized clinical trials:
  1. Donovan E, BleakleyN, DenholmE, et al. Randomisedtrial of standard 2D radiotherapy (RT) versus intensity modulated radiotherapy (IMRT) in patients prescribed breast radiotherapy. RadiotherOncol. 2007 Mar;82(3):254-64.
  - 306 patients were randomized to 2D or 3D IMRT
  - 2D-arm patients were 1.7 times higher than IMRT patients to have changes in breast appearance

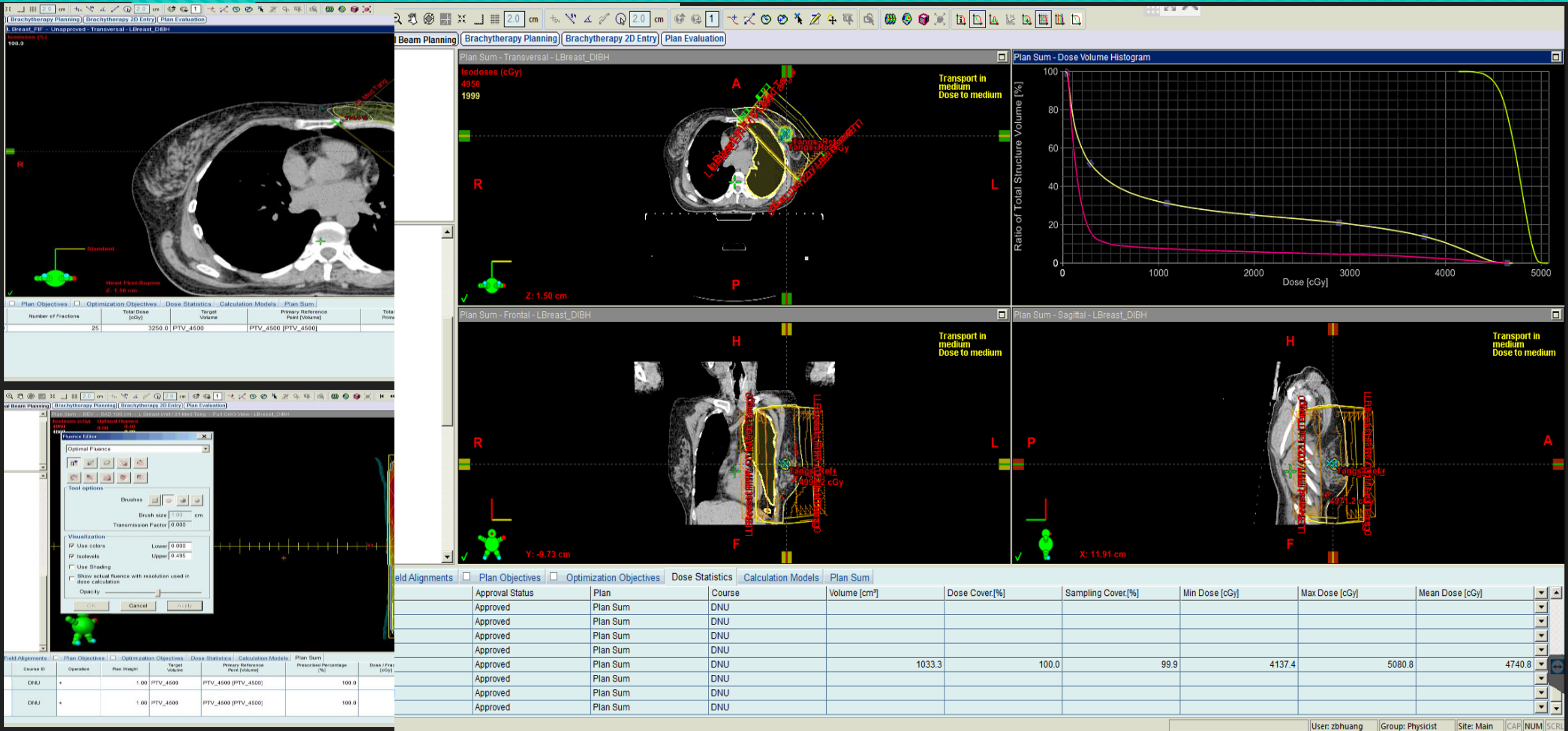
Breast Cancer

- Randomized clinical trials:
  1. PignolJP, OlivottoI, RakovitchE, et al.   A multicenter randomized trial of breast intensity-modulated radiation therapy to reduce acute radiation dermatitis.J ClinOncol. 2008 May 1;26(13):2085-92.
  - 358 patients were randomized in a multicenter double-blind clinical trial with either IMRT or 2D treatment planning
  - Moist desquamation in the IMRT group was 31.2% vs 47.8% (p=0.002)

Breast Cancer – Dose Constraint to Target and OARs

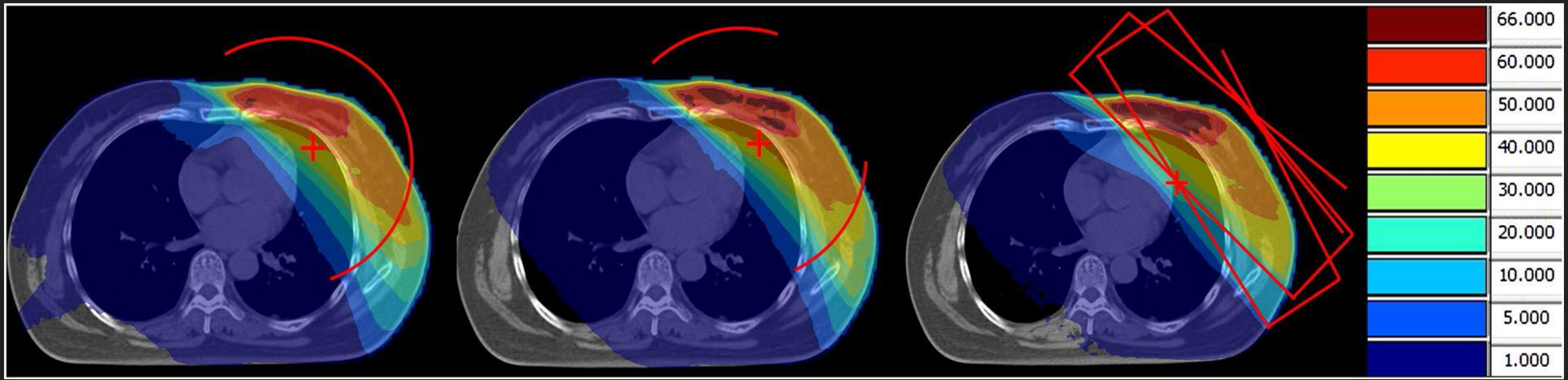
Organ	Constraint
Chest Wall	V90 ≥ 90.0%
Breast	V100 ≥ 90.0% V95 ≥ 95.0% V105 ≤ 40.0% V110 ≤ 10.0%
IMN Nodes	V80 ≥ 100.0%
SCV	V90 ≥ 90.0%
Ax Nodes	V90 ≥ 90.0%
Contralateral Breast	V5Gy ≤ 15.0%
Ipsilateral Lung	V20Gy ≤ 45.0% V30Gy ≤ 35.0%
Whole Lung	V20Gy ≤ 25.0% V30Gy ≤ 20.0%
Heart	V5Gy ≤ 40.0% (≤ 50.0% for left-sided tumors) V20Gy ≤ 20.0%

Breast Cancer - Fluence



Breat Cancer - VMAT, 2D, IMRT

- Dose distribution in a selected transversal plane and the beam arrangement in three techniques
  - Scientific Reports | 7: 14748 | DOI:10.1038/s41598-017-15307-7
- In conclusion, 2TARC was shown to be the optimal treatment technique amongst the studied techniques for patients with left-sided breast cancer after BCS, if they chose the photon therapy
- The doses to OARs were shown to increase significantly for the patients with inner quadrant tumor

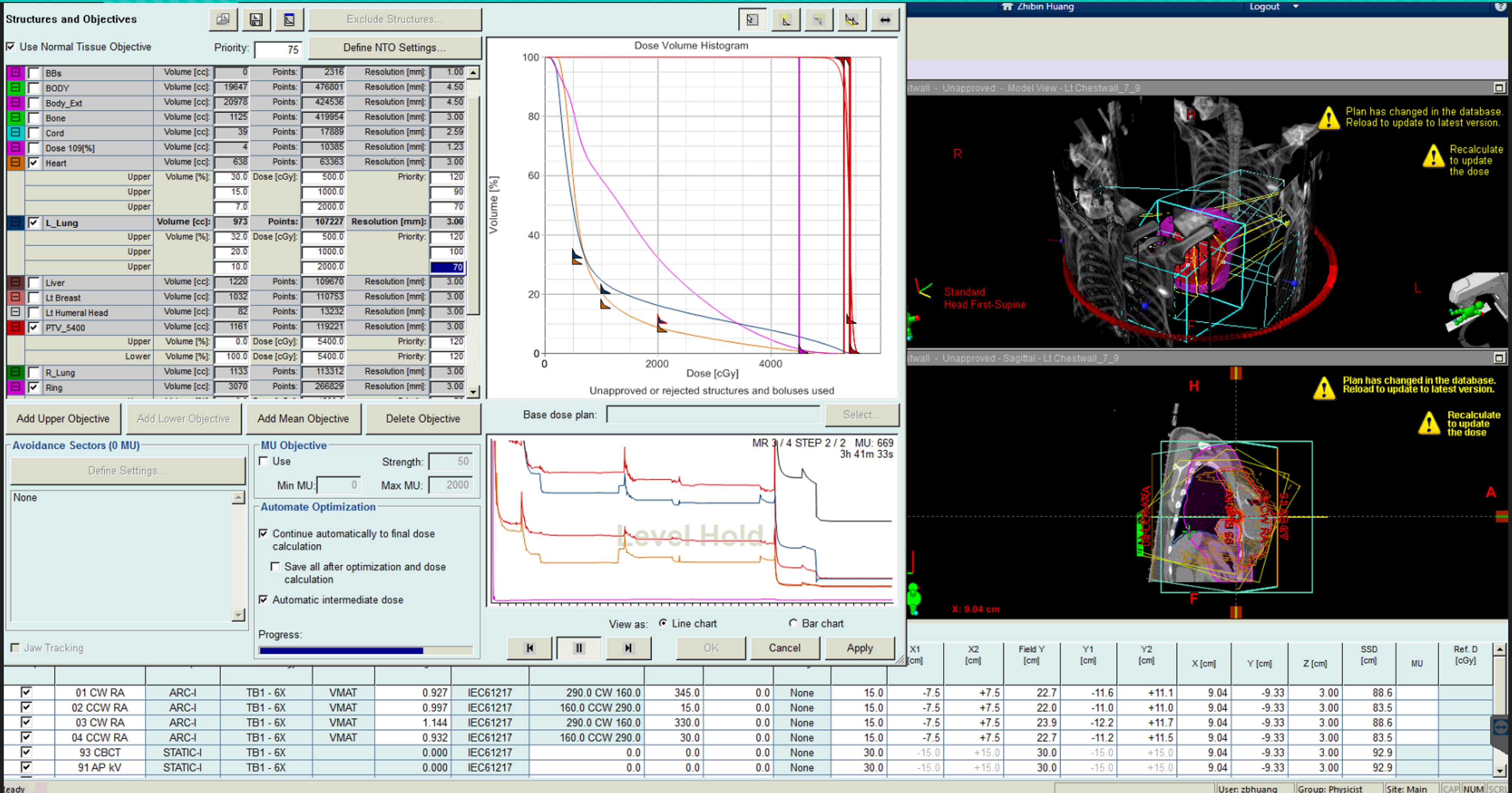


Breast Cancer - Doses to OARs

			Plan A	PlanB	Plan C	P value A Vs B	B Vs C	A Vs C
Lung_Right	Dmean(Gy)	mean ± SD	2.58 ± 0.54	1.39 ± 0.18	1.15 ± 0.14	0.000	0.000	0.000
		max/min	3.33/1.77	1.74/1.21	1.34/0.95			
Spinal cord	Dmax(Gy)	mean ± SD	3.60 ± 0.86	2.16 ± 1.13	1.25 ± 0.17	0.000	0.000	0.000
		max/min	4.80/2.15	5.07/1.24	1.57/1.01			
Breast_Right	Dmean(Gy)	mean ± SD	2.60 ± 0.69	1.74 ± 0.38	1.51 ± 0.54	0.000	0.028	0.000
		max/min	4.08/1.82	2.38/1.42	2.50/1.06			
	Dmax(Gy)	mean ± SD	5.73 ± 1.66	4.95 ± 1.32	5.38 ± 2.06	0.023	0.289	0.246
		max/min	9.51/4.61	8.39/3.31	9.67/3.15			
Lung_Left	V5(%)	mean ± SD	41.22 ± 8.86	38.18 ± 4.45	41.73 ± 6.12	0.206	0.092	0.852
		max/min	56.5/33.6	46.4/33.5	51.7/34.6			
	V10(%)	mean ± SD	23.53 ± 4.52	23.65 ± 3.68	28.10 ± 5.22	0.895	0.008	0.004
		max/min	31/18.1	30.5/19.3	36.2/22.9			
	V20(%)	mean ± SD	13.83 ± 2.93	15.28 ± 2.92	17.54 ± 4.16	0.047	0.035	0.008
		max/min	18.5/9.6	20.5/11.5	26.2/12.1			
	Dmean(Gy)	mean ± SD	9.23 ± 1.51	9.52 ± 1.63	10.20 ± 1.90	0.348	0.036	0.009
		max/min	11.67/7.21	12.92/7.47	13.81/7.68			
Heart	V5(%)	mean ± SD	28.97 ± 9.62	23.84 ± 8.33	24.35 ± 7.29	0.070	0.936	0.225
		max/min	49.5/17.4	35.5/10.6	35.1/12.3			
	V10(%)	mean ± SD	11.43 ± 4.49	10.72 ± 2.90	15.42 ± 5.34	0.702	0.012	0.055
		max/min	19.1/7	15.2/6.58	21.9/7.3			
	V20(%)	mean ± SD	4.71 ± 1.72	5.41 ± 2.02	8.30 ± 3.89	0.525	0.008	0.003
		max/min	8.4/2.9	8.1/2.7	12.9/4.3			
	Dmean(Gy)	mean ± SD	5.83 ± 0.86	5.38 ± 1.01	5.87 ± 1.27	0.047	0.035	0.917
		max/min	7.33/5.05	6.81/4.18	8.32/4.20			
Body	V5(%)	mean ± SD	22.80 ± 4.05	17.04 ± 3.12	17.21 ± 2.67	0.000	0.784	0.000
		max/min	29.19/17.72	21.87/13.43	20.35/13.93			

Table 2. Comparison of the doses to OARs (Plan A: 1ARC/Plan B: 2TARC/PlanC: 4IMRT, paried T test).

Breast Cancer – VMAT



Breast Cancer - VMAT
-Bolus for optimization

VMAT Planning Optimization

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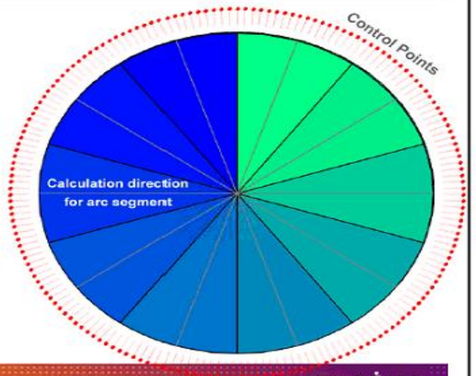
Progressive Resolution

- Optimization performed in 4 resolution levels
  - The multi-resolution scheme applies to calculation directions only
  - The number of calculation directions doubles at each resolution level
  - Number of control points does not change
    - Algorithm flexibility preserved through optimization
    - Control points within single calculation direction merged into "fluence" for given calculation direction



The optimization is performed in 4 resolution levels.
The number of control points does not change during the optimization. It is set at the very beginning of optimization.

- The initial MLC shapes are conformed to the targets.
- The initial dose rates are equal for all dose calculation segments.
- Larger MLC changes are available during the earlier levels. The size of the MLC adjustments diminish as the optimization progresses through the levels.
- The DVH is equally accurate for OARs and targets from the very beginning of optimization.

Only the calculation directions follow the multi-resolution scheme.

- The dosimetric accuracy increases with the resolution level.
- Control points which "belong" to a calculation direction are used to calculate fluence. This is used for a dose calculation from the calculation direction.

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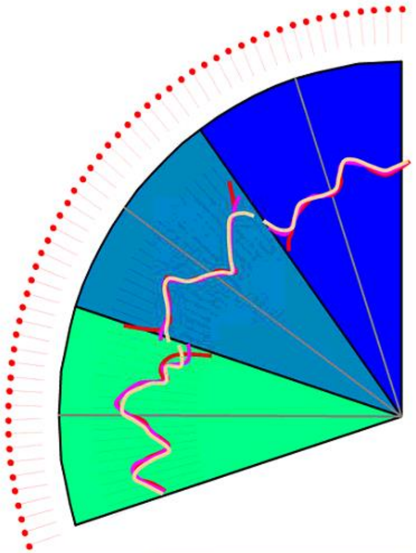
29 / 489 200%

Steps

- Dose in calculation segment is calculated from combined fluence through MLCs at control points within sector
- Embedded leaf sequencing done at each optimization iteration
- All machine limits are enforced within calculation direction
- At the beginning calculation directions are independent
  - As if delivered separately not in continuous rotation
- Each resolution level divided into steps
- Each step increases dependence between calculation directions gradually enforcing machine limits at the calculation direction interface



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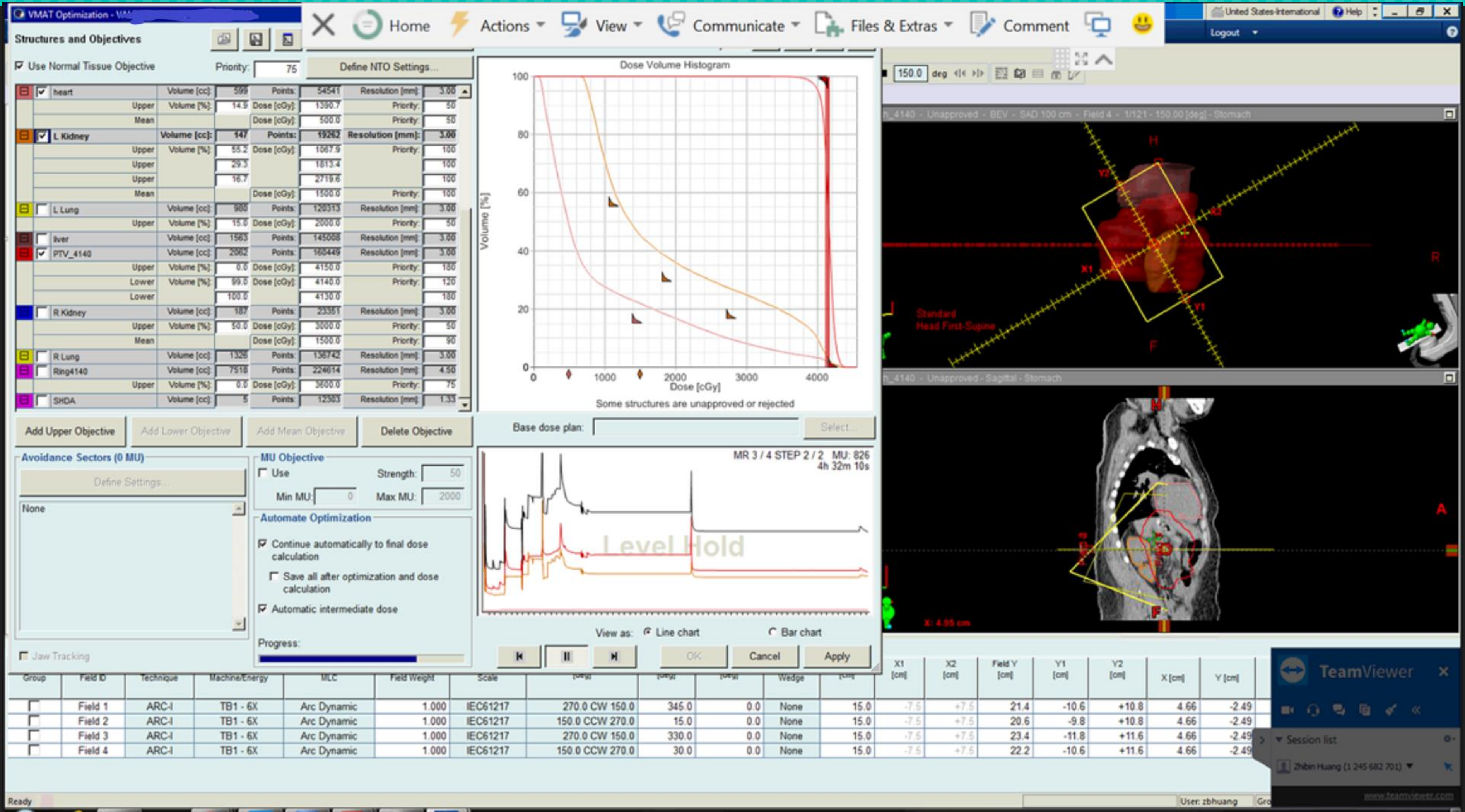
Optimization - Calculation



Comparison in optimization with and without levels hold

- 5 patients were included
- PTV (Min Dose, Max Dose, Mean Dose)
- Dose to critical structures (heart, ipsilateral lung, contralateral lung)

Dose to Target/OARs	PTV (Rx:4500cGy)			Heart			Ipsilateral Lung			Contralateral Lung		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Without levels hold	3663	5303	4888	144.9	2871	524	87.7	4731	1074	58.3	1897	334
With levels hold	3524	5010	4711	148.2	2807	490	82.8	4579	1008	52.8	1892	314

Sector Avoidance

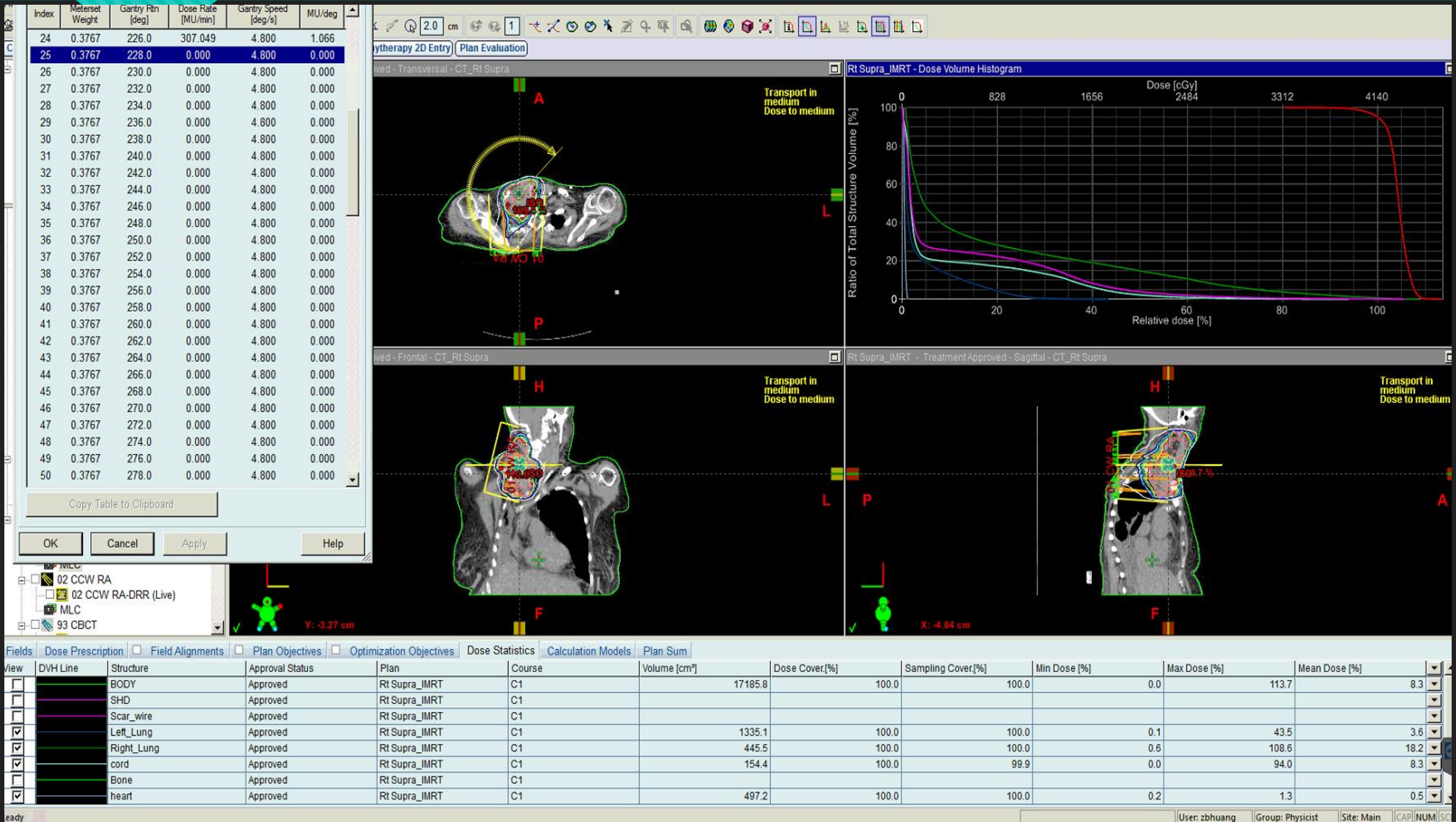
- To reduce uncertainty including CT number, setup
  - Critical structures
    - e.g. hippocampus during whole-brain radiotherapy prevents cognitive side effects
  - Dental filling material (DFM)
    - The backscatter from the DFM for a single, parallel-opposed fields, and RapidArc treatment technique was found significant
    - The measured backscatter upstream dose from DFM for a single-field was 22% higher than without the DFM, whereas the downstream dose was lower by 14%

1. Med Phys. 2013 Aug;40(8):081714. doi: 10.1118/1.4816307.

Sector Avoidance

- To reduce uncertainty including CT number, setup
  - Hip Prothesis
    - Artifacts cause CT number uncertainty
  - Setup irreproducibility
    - e.g. daily pannus variability in set up, causing Dose differences between planned and re-calculated rectal wall mean dose and the V_{24Gy} were numerically larger in the absence of the avoidance sector for all fractions and for both simulated pannus variations, with maximum changes of 2.6% and 1.3%.
      1. Med Dosim. 2019 Summer;44(2):179-182. doi: 10.1016/j.meddos.2018.05.003. Epub 2018 Aug 16.

Sector Avoidance – example
-RT super clavicular mass



Head&Neck

- PTV coverage:
  - 95% of PTV covered by 100% Rx
- More than 20 critical structures to contour
- Dose Constraints – RTOG

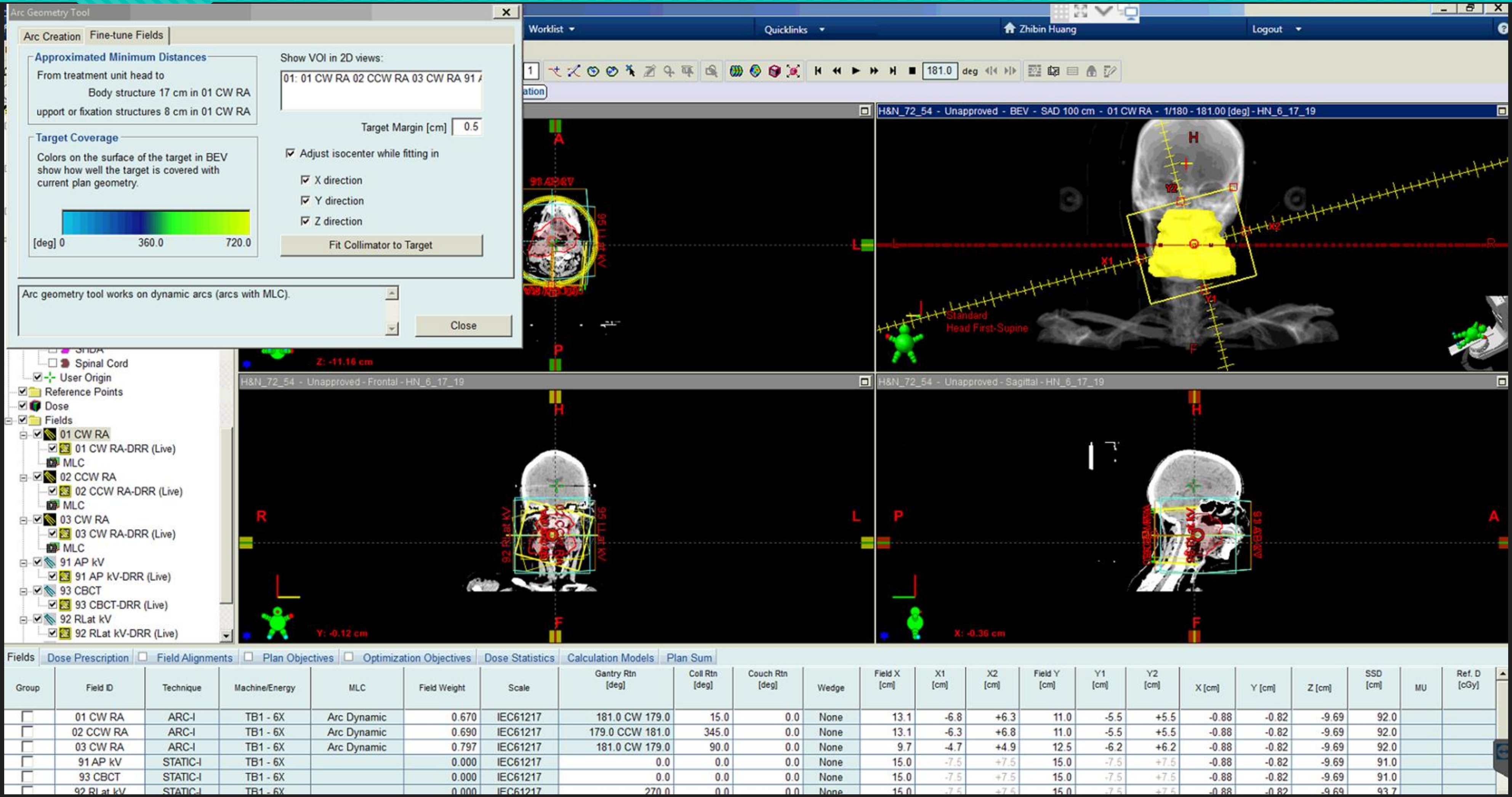
  Spinal Cord: Max < 45 Gy, 1cc < 45Gy

  Brainstem: Max < 55 Gy, 1% <54 Gy

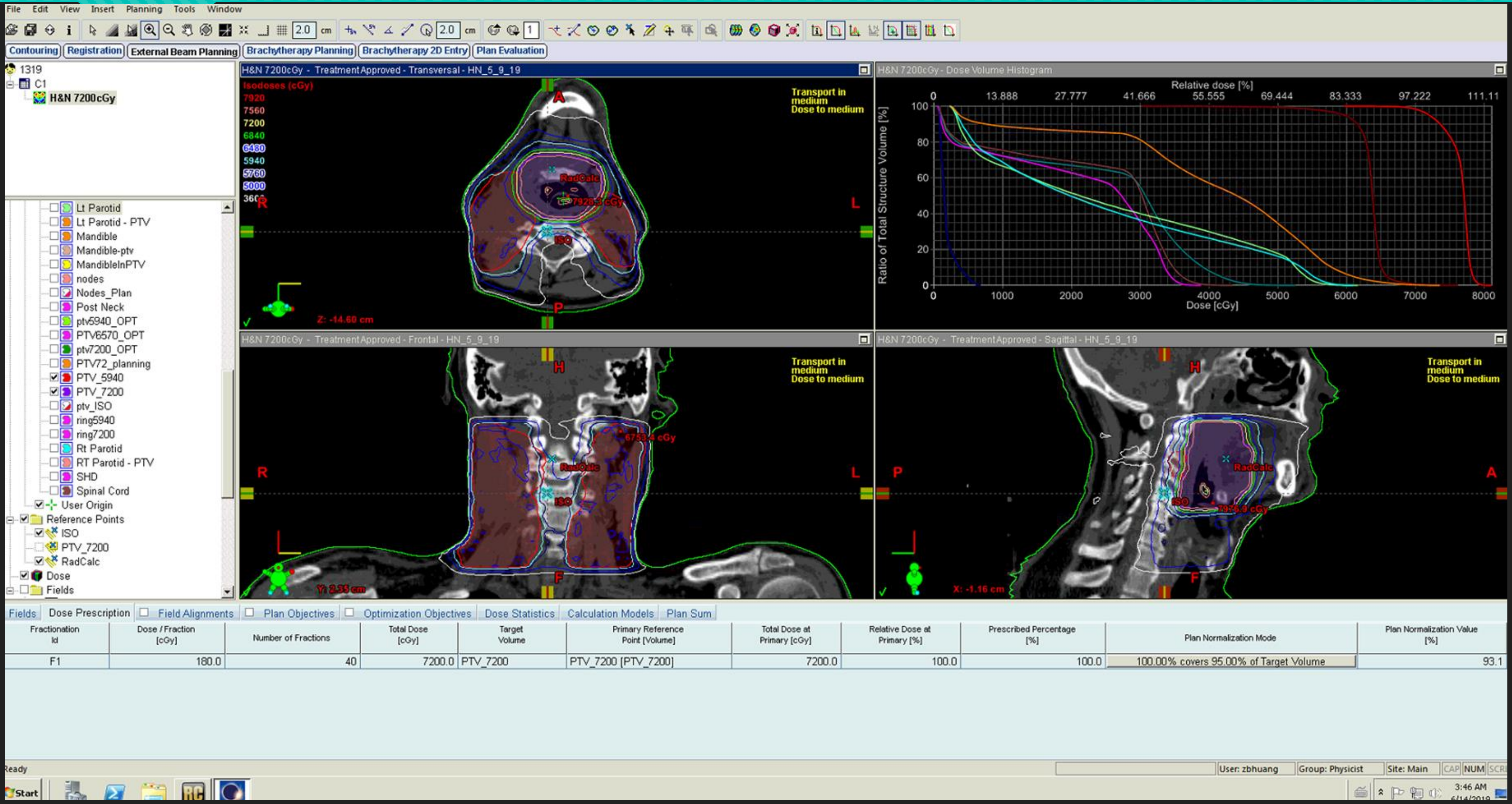
  Parotid glands: mean dose < 26 Gy

  Optic structures: Max < 54 Gy
- Example: H&N treatment
  - I. Physician wants 72 Gy to target, 59.4Gy to lymph nodes
  - II. Meet dose constraints

Head&Neck


Arc Geometry Tool
Arc Creation
Fine-tune Fields
Approximated Minimum Distances
From treatment unit head to
Body structure 17 cm in 01 CW RA
upport or fixation structures 8 cm in 01 CW RA
Target Coverage
Colors on the surface of the target in BEV show how well the target is covered with current plan geometry.
[deg] 0
360.0
720.0
Show VOI in 2D views:
Target Margin [cm]
0.5
Adjust isocenter while fitting in
X direction
Y direction
Z direction
Fit Collimator to Target
Arc geometry tool works on dynamic arcs (arcs with MLC).
Close
Worklist
Quicklinks
Zhibin Huang
Logout
H&N_72_54 - Unapproved - BEV - SAD 100 cm - 01 CW RA - 1/180 - 181.00 [deg] - HN_6_17_19
H&N_72_54 - Unapproved - Frontal - HN_6_17_19
H&N_72_54 - Unapproved - Sagittal - HN_6_17_19
Standard
Head First-Supine
Spinal Cord
User Origin
Reference Points
Dose
Fields
01 CW RA
01 CW RA-DRR (Live)
MLC
02 CCW RA
02 CCW RA-DRR (Live)
MLC
03 CW RA
03 CW RA-DRR (Live)
MLC
91 AP kV
91 AP kV-DRR (Live)
93 CBCT
93 CBCT-DRR (Live)
92 RLat kV
92 RLat kV-DRR (Live)
Fields
Dose Prescription
Field Alignments
Plan Objectives
Optimization Objectives
Dose Statistics
Calculation Models
Plan Sum
Group | Field ID | Technique | Machine/Energy | MLC | Field Weight | Scale | Gantry Rtn [deg] | Coll Rtn [deg] | Couch Rtn [deg] | Wedge | Field X [cm] | X1 [cm] | X2 [cm] | Field Y [cm] | Y1 [cm] | Y2 [cm] | X [cm] | Y [cm] | Z [cm] | SSD [cm] | MU | Ref. D [cGy]
01 CW RA | ARC-I | TB1 - 6X | Arc Dynamic | 0.670 | IEC61217 | 181.0 CW 179.0 | 15.0 | 0.0 | None | 13.1 | -6.8 | +6.3 | 11.0 | -5.5 | +5.5 | -0.88 | -0.82 | -9.69 | 92.0
02 CCW RA | ARC-I | TB1 - 6X | Arc Dynamic | 0.690 | IEC61217 | 179.0 CCW 181.0 | 345.0 | 0.0 | None | 13.1 | -6.3 | +6.8 | 11.0 | -5.5 | +5.5 | -0.88 | -0.82 | -9.69 | 92.0
03 CW RA | ARC-I | TB1 - 6X | Arc Dynamic | 0.797 | IEC61217 | 181.0 CW 179.0 | 90.0 | 0.0 | None | 9.7 | -4.7 | +4.9 | 12.5 | -6.2 | +6.2 | -0.88 | -0.82 | -9.69 | 92.0
91 AP kV | STATIC-I | TB1 - 6X | 0.000 | IEC61217 | 0.0 | 0.0 | 0.0 | None | 15.0 | -7.5 | +7.5 | 15.0 | -7.5 | +7.5 | -0.88 | -0.82 | -9.69 | 91.0
93 CBCT | STATIC-I | TB1 - 6X | 0.000 | IEC61217 | 0.0 | 0.0 | 0.0 | None | 15.0 | -7.5 | +7.5 | 15.0 | -7.5 | +7.5 | -0.88 | -0.82 | -9.69 | 91.0

Head&Neck


File Edit View Insert Planning Tools Window
Contouring
Registration
External Beam Planning
Brachytherapy Planning
Brachytherapy 2D Entry
Plan Evaluation
1319
C1
H&N 7200cGy
H&N 7200cGy - TreatmentApproved - Transversal - HN_5_9_19
H&N 7200cGy - Dose Volume Histogram
H&N 7200cGy - TreatmentApproved - Frontal - HN_5_9_19
H&N 7200cGy - TreatmentApproved - Sagittal - HN_5_9_19
Isodoses (cGy)
7920
7560
7200
6840
6480
5940
5760
5000
Transport in medium
Dose to medium
Relative dose [%]
Ratio of Total Structure Volume [%]
Dose [cGy]
Lt Parotid
Lt Parotid - PTV
Mandible
Mandible-ptv
MandibleInPTV
nodes
Nodes_Plan
Post Neck
ptv5940_OPT
PTV6570_OPT
ptv7200_OPT
PTV72_planning
PTV_5940
PTV_7200
ptv_ISO
ring5940
ring7200
Rt Parotid
RT Parotid - PTV
SHD
Spinal Cord
User Origin
Reference Points
ISO
PTV_7200
RadCalc
Dose
Fields
Fields
Dose Prescription
Field Alignments
Plan Objectives
Optimization Objectives
Dose Statistics
Calculation Models
Plan Sum
Fractionation Id | Dose / Fraction [cGy] | Number of Fractions | Total Dose [cGy] | Target Volume | Primary Reference Point [Volume] | Total Dose at Primary [cGy] | Relative Dose at Primary [%] | Prescribed Percentage [%] | Plan Normalization Mode | Plan Normalization Value [%]
F1 | 180.0 | 40 | 7200.0 | PTV_7200 | PTV_7200 [PTV_7200] | 7200.0 | 100.0 | 100.0 | 100.00% covers 95.00% of Target Volume | 93.1
Ready
User: zbhuang
Group: Physicist
Site: Main
Start

Pelvis/Prostate

- Rectum
  - D40 ≤ 65 Gy,
  - D30 ≤ 70 Gy,
  - D10 ≤ 75 Gy,
  - Dmax* ≤ 81 Gy (*Dmax = dose to clinically significant volume)
- Bladder
  - D30 ≤ 70 Gy,
  - Dmax* ≤ 81 Gy

Brain Metastasis

- Tolerance doses:
  - Optic nerves: Max dose < 54Gy
  - Lens: Max dose < 6 Gy
  - Chiasm: Max dose < 54 Gy
  - Brainstem: Max dose < 54 Gy
  - Eyes: Max dose < 45 Gy
  - Cochlea: Mean dose < 45 Gy

SRS/SBRT Lung Cancer

- RTOG 0813, RTOG 0915
- Prescription: 50Gy/5fx, 48Gy/4fx, 54Gy/3fx
- Dose to target/critical structures (NRG-BR001, Timmerman)
- R50, R100, D2cm
- Couch kick, collimator angle, gantry angle

SRS/SBRT RTOG Guidelines

- **Multiple metastatic lesions: NRG-BR001**
- **SRS/SRT Brain: RTOG 90-05, RTOG 0933**
- **SRS Spine: RTOG 0631**
- **SBRT Prostate: RTOG 0938**

Plan Evaluation

- PTV coverage is achieved?
  - Define endpoints such as 95% of PTV covered by 100% Rx
- Dose distributions on every CT slice
  - Rx, Max dose, Min dose
- Dose constraints meet the criteria?
  - Dose volume histogram (DVH)
- Refer to AAPM TG-100, TG-275, RTOG guidelines

How to improve the plan

- If the plan is not acceptable, what to do?
  - Image quality
  - Anatomy
  - Beam angle selection
  - Collimator angle selection
  - Sector avoidance
  - Bolus - buildup
  - Base dose plan
  - Single isocenter versus multiple isocenters

Imaging

- Image quality - Artifacts caused by
  - Hip prosthesis
  - Dental filling
  - BBs
  - Patient motions
- Image registration
  - PET/CT
  - MRI

Anatomy

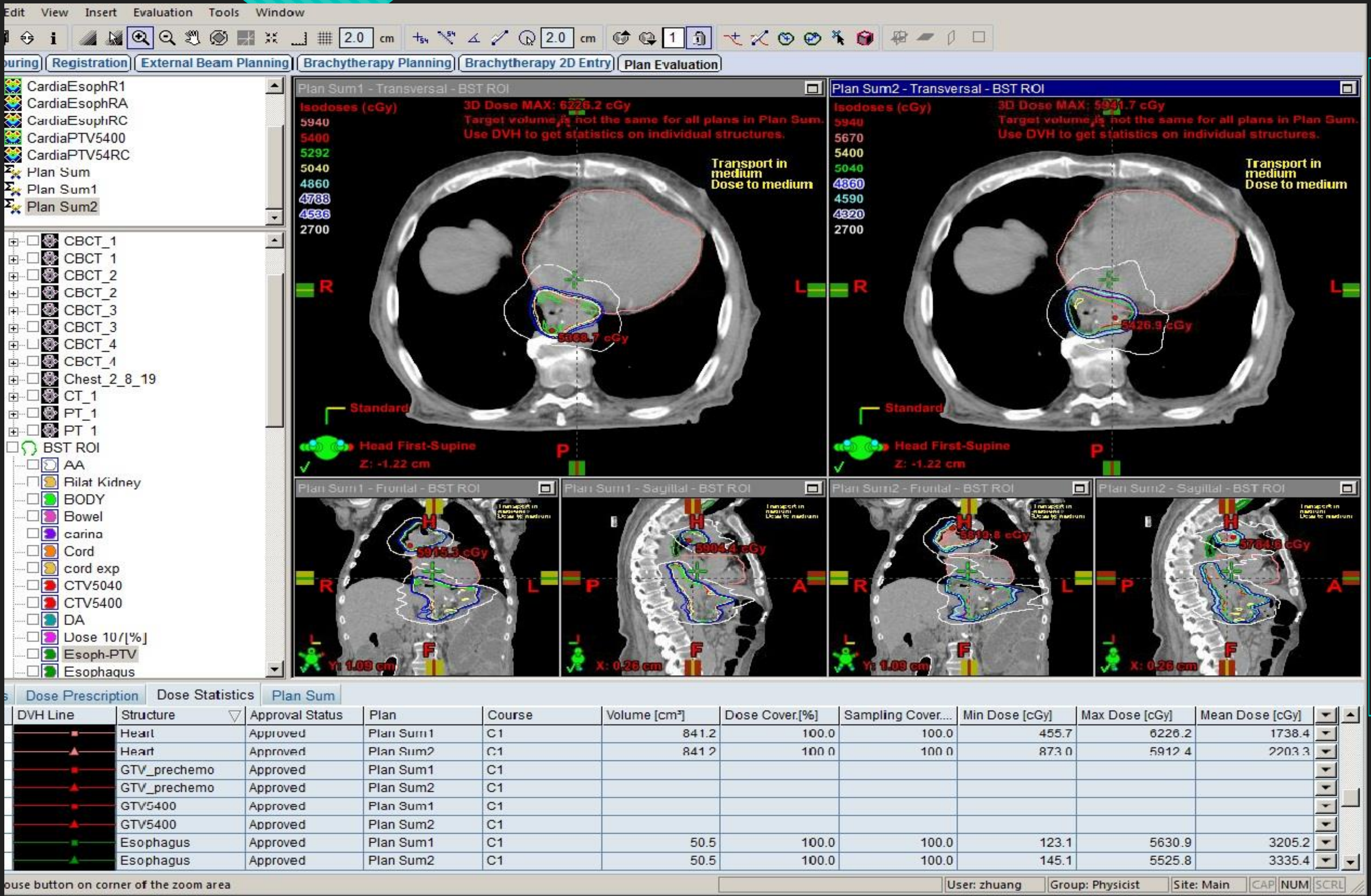
- Variation in target volume and location
- PTV too close to skin
  - a volume at least 3mm away from skin surface
- Geometry limitations
  - PTV and critical structure overlaying

Beam angle selection

- Avoid critical structures
- Maintain large beam separation if possible
- Use shortest pathway to irradiate the tumor
  - Beam angle selection is important if the tumor is not centrally located

Collimator angle

Single- vs Multiple-ISO



- **"Exposure of the heart to ionizing radiation during radiotherapy for breast cancer increases the subsequent rate of ischemic heart disease. The increase is proportional to the mean dose to the heart, begins within a few years after exposure, and continues for at least 20 years. "**

N Engl J Med 2013; 368:987-998
DOI: 10.1056/NEJMoa1209825

Single- vs multiple-ISO radiosurgery
Poster Number: PO-GePV-T-336

Summary

- Review photon beam characteristics
- Present dosimetric skills for treatment planning
  - breast cancer
  - head&Neck cancer
  - SBRT lung cancer, etc.
- Evaluate treatment plans
- Improve treatment plan quality

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- Julio Diaz, MD, University of Puerto Rico
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- Yuanming Feng, PhD, DABR, East Carolina University

Thank you very much!

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