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May 16, 2015

SBRT Clinical Protocols: Treatment Planning and Delivery Considerations

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The University of Chicago

University of Chicago SBRT Experiences

- Oligometastases trial (2004-2010)
  - Phase I Trial
  - 5 sites, 3 x 8Gy → 18Gy
- Large Metastases (2005 – now)
  - 5 Gy x 10
- Lung
  - Primary Tumors (<4.5 cm):
  - 12 Gy or 10 Gy x5
- Liver
  - Mets: 10 Gy x 5 or 20 Gy x3
  - HCC: 30-50 Gy in 5 fx (Veff)
- Spinal Mets
  - 16 Gy-18 Gy: Single fraction
  - 8 Gy x 3

Conventional RT vs. SBRT

Characteristic	Conventional RT	SBRT
Dose / Fraction	1.8 – 3 Gy	6 – 30 Gy
No. of Fractions	10 – 30	1-5
Target definition	CTV / PTV gross disease + clinical extension: tumor may not have a sharp boundary.	GTV / CTV / ITV/ PTV well-defined tumors: GTV=CTV
Margin	Centimeters	Millimeters

(From Table 1: AAPM TG 101)

Although SBRT employs similar basic principles as in conventional modalities including IMRT and IGRT, its extreme hypofractionated treatment delivery demands the utmost consideration for safety!

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SBRT Requires

- *Secure immobilization*
  - *Stereotactic body frame (?) Reliable IGRT friendly immobilization*
- *Well defined tissue (tumor and normal) delineation*
  - *Multi-modality, motion compensated imaging*
- *Reliable mechanisms for generating focused, sharply delineated dose distributions*
  - *Non-opposing, well collimated co-planar and non-coplanar beam arrangements*
  - *3DCRT or IMRT /VMAT techniques and optimal beam margins*
- *Reliable mechanisms to control/compensate organ motion*
  - *Breath hold techniques or gating*
- *Accurate and precise targeting*
  - *Image guided targeting*
- *Few fractions, high dose*

RTOG Clinical Trials: SBRT

- RTOG 0236: Phase II Lung: (HOMOGENEOUS DOSE CALC)
- RTOG 0915: Phase II Lung
- RTOG 0813: Phase II Lung
- RTOG 0631: Phase II Spine
- RTOG 0438: Phase II Liver
- NRG BR001: Phase I Multiple Metastases

Provide Treatment Planning Guidelines for

- Dose Prescription/Fractionation
- Target Coverage
- Normal Tissue Dose Limits

Treatment Planning for SBRT

- Ablative intent for SBRT
- Dose inhomogeneity inside the PTV is acceptable
- Maximum point dose up to 160% of Prescription Dose within PTV is common for SBRT plans.
- Minimize the volume of normal tissue irradiation outside of the PTV
- MUST respect all normal tissue dose limits

If beam margin is close to beam penumbra (5-6 mm)→
Homogeneous PTV dose, Maximum dose about 110% of Prescription Dose (PD).
Dose fall off outside PTV is slow

If beam margin is much less than beam penumbra (0-2 mm) →
Inhomogeneous PTV dose, Maximum dose ~ 125% or more of PD.
Dose fall off outside PTV is fast

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A 20Gy x 3 plan is quite different from a 2Gy x 30 plan: Example small lung lesion (PTV = 33cc)

	SBRT	Conventional Fractionated	
# of Beams	11	11	3
Beam Margin (mm)	1	5	5
PD per fraction	20 Gy	2 Gy	2 Gy
Max PTV Dose (%)	124.2%	110.8%	110.0%
$V_{100\%}$	38.6 cc	44.3 cc (5.7 cc more)	87.5 cc (48.9 cc more)
$V_{50\%}$ ($R_{50\%}$)	146.3 cc (4.4)	212.4 cc (6.4) (66 cc more)	417.3 cc (12.6) (271 cc more)
$V_{25\%}$	630.4 cc	799.2 cc (169 cc more)	756.8 cc (126 cc more)
50% PD	10 Gy	1 Gy	1 Gy

All Plans normalized to PTV V100% = 95%

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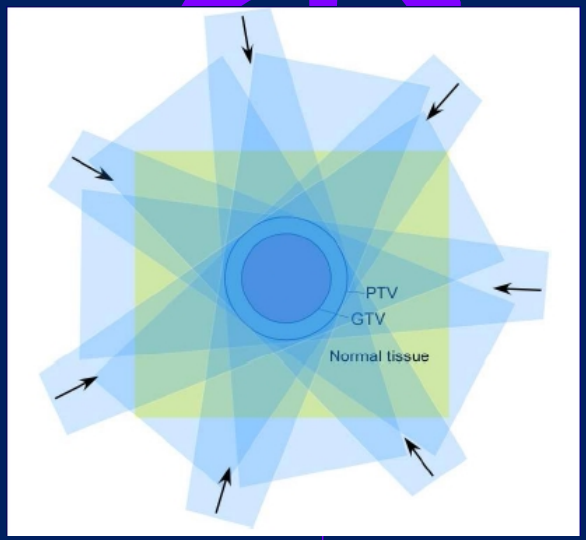
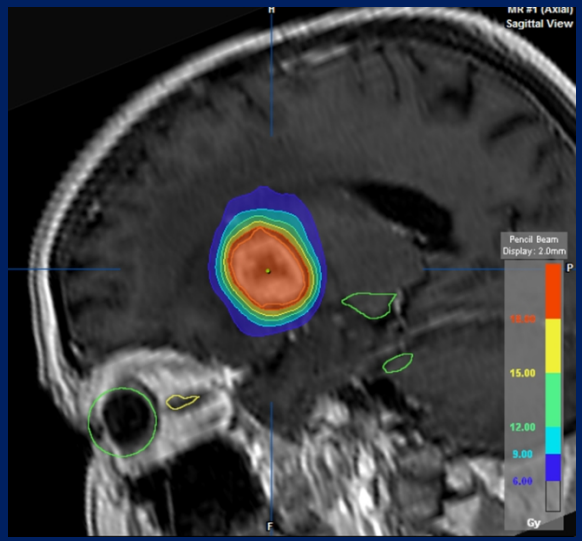
SBRT and SRS are quite similar in planning

- Inhomogeneous Dose inside PTV
- Sharp Dose Fall Off outside PTV
- Multiple non-coplanar beams or arcs
- However, SBRT has more limited non-coplanar beam placement due to collision issues

Intracranial Radiosurgery

- *Small* volumes of tissues *within the brain* are treated with *large* doses delivered in a *single* fraction
- Normal tissues are protected by the rapid dose falloff and by delivering the treatment with *high precision*
- *many well-separated non-opposing beams*





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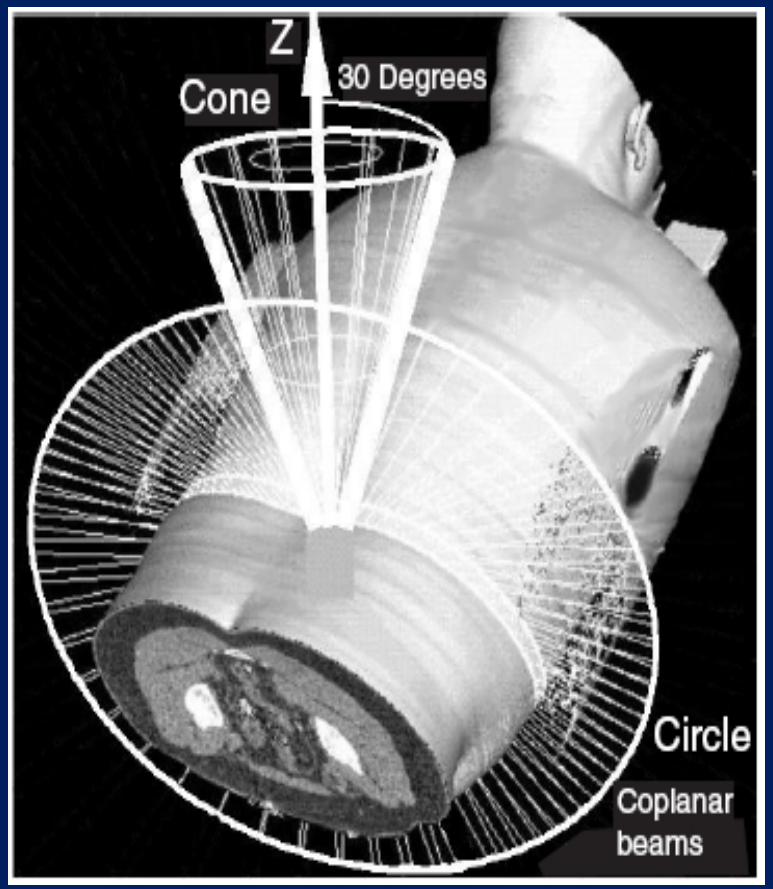
Limited non-coplanar Beam Geometry for SBRT



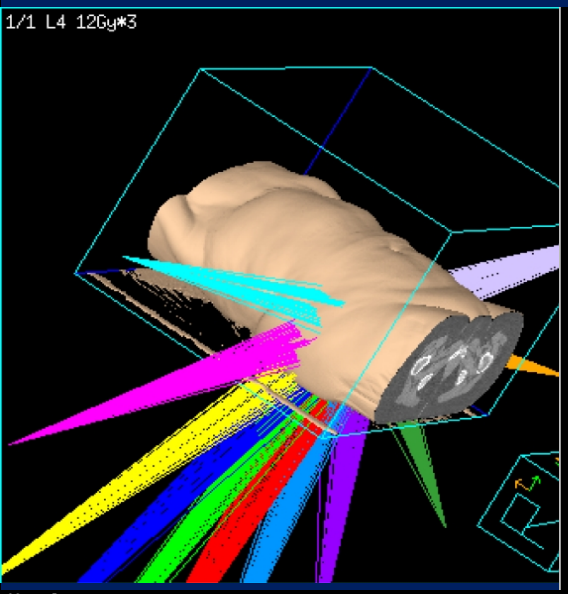
Restricted deliverable beam space for SBRT(Liu et al PMB, 2004)

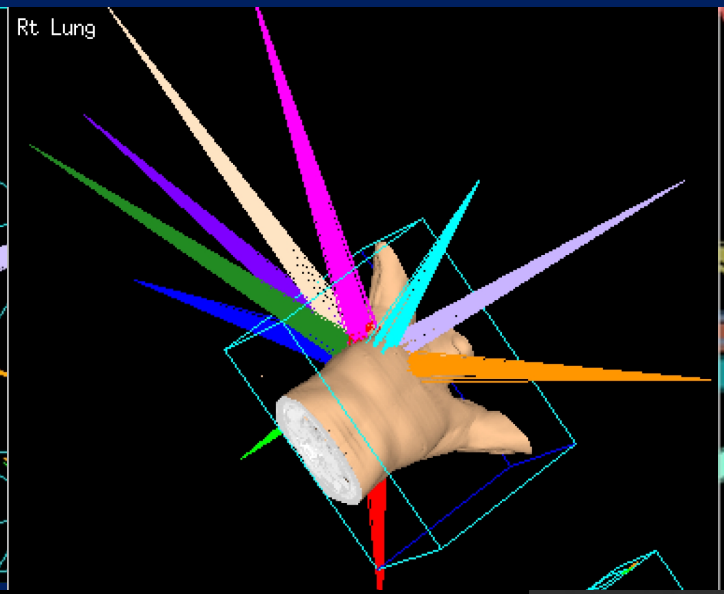
Lung: geometrically optimized beams

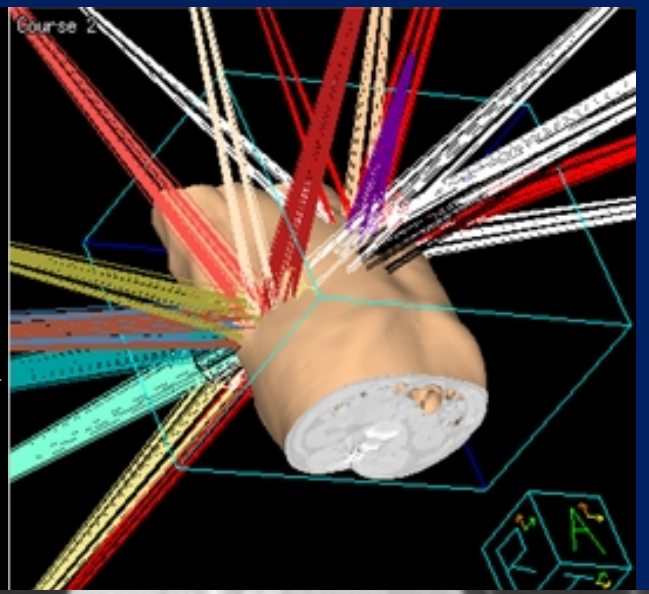
	Prescription isodose (%)	PITV	Effective gradient (mm)
Non-coplanar plan 11 beams	85	1.22	10.9
Coplanar plan 11 beams	83	1.22	11.8

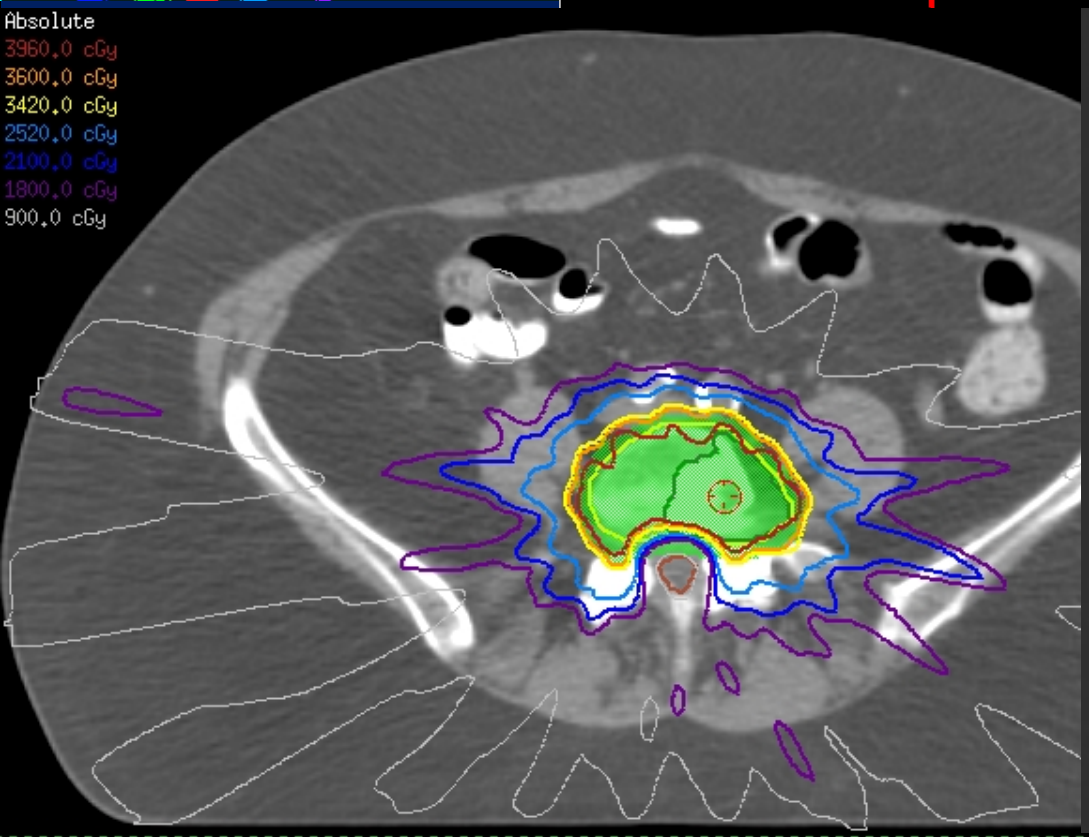
Liver: geometrically optimized beams

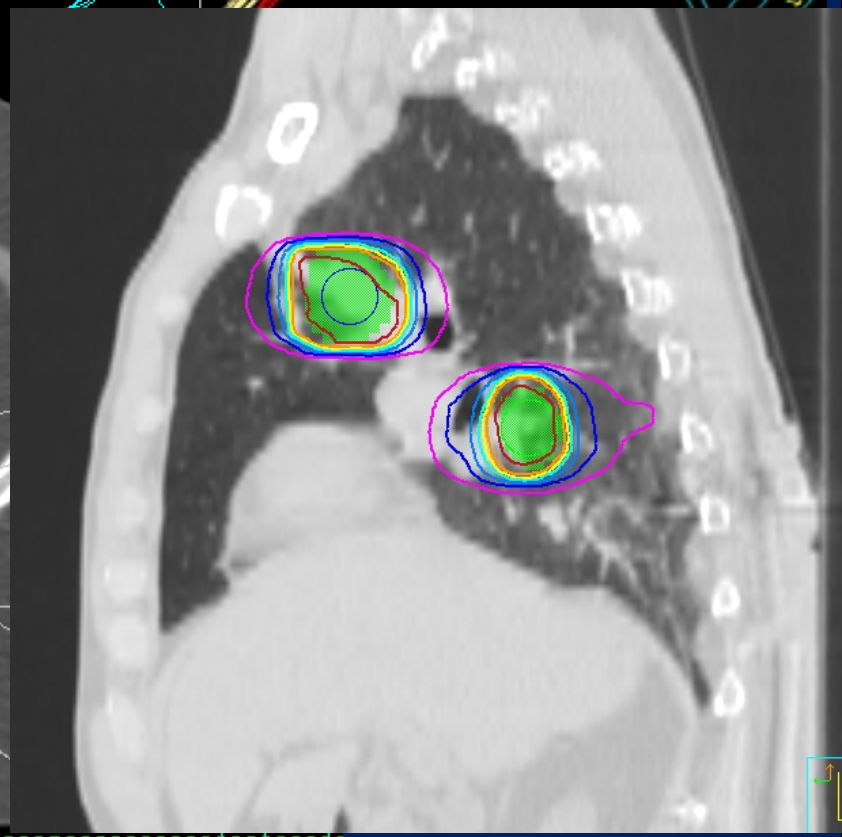
	Prescription isodose (%)	PITV	Effective gradient (mm)
Non-coplanar plan 11 beams	84	1.13	14.7
Coplanar plan 11 beams	83	1.10	14.5


1/1 L4 12Gy*3


Rt Lung


Course 2


Absolute
3960.0 cGy
3600.0 cGy
3420.0 cGy
2520.0 cGy
2100.0 cGy
1800.0 cGy
900.0 cGy



SBRT Treatment Planning Guidelines
(RTOG 0813 and 0915 lung protocols)

- **Maximum Dose:** normalized to 100%, must be within PTV
- **Prescription Isodose:** must be ≥ 60% and < 90% of the maximum dose
- **PTV Coverage:**
  - V100%PD = 95%
  - V90%PD > 99%
- **High Dose Spillage**: The cumulative volume of all tissue outside the PTV receiving a dose > 105% of prescription dose should be no more than 15% of the PTV volume
- **Intermediate Dose Spillage:** The falloff gradient beyond the PTV extending into normal tissue structures must be rapid in all directions and meet the criteria in Table1
- **All normal tissue dose limits need to be respected**

Table 1: Conformality of Prescribed Dose for Calculations Based on Deposition of Photon Beam Energy in Heterogeneous Tissue

PTV Volume (cc)	Ratio of Prescription Isodose Volume to the PTV Volume		Ratio of 50% Prescription Isodose Volume to the PTV Volume, $R_{50\%}$		Maximum Dose (in % of dose prescribed) @ 2 cm from PTV in Any Direction, D_{2cm} (Gy)		Percent of Lung Receiving 20 Gy Total or More, V_{20} (%)	
	Deviation		Deviation		Deviation		Deviation	
	None	Minor	None	Minor	None	Minor	None	Minor
1.8	<1.2	<1.5	<5.9	<7.5	<50.0	<57.0	<10	<15
3.8	<1.2	.<1.5	<5.5	<6.5	<50.0	<57.0	<10	<15
7.4	<1.2	<1.5	<5.1	<6.0	<50.0	<58.0	<10	<15
13.2	<1.2	<1.5	<4.7	<5.8	<50.0	<58.0	<10	<15
22.0	<1.2	<1.5	<4.5	<5.5	<54.0	<63.0	<10	<15
34.0	<1.2	<1.5	<4.3	<5.3	<58.0	<68.0	<10	<15
50.0	<1.2	<1.5	<4.0	<5.0	<62.0	<77.0	<10	<15
70.0	<1.2	<1.5	<3.5	<4.8	<66.0	<86.0	<10	<15
95.0	<1.2	<1.5	<3.3	<4.4	<70.0	<89.0	<10	<15
126.0	<1.2	<1.5	<3.1	<4.0	<73.0	>91.0	<10	<15
163.0	<1.2	<1.5	<2.9	<3.7	<77.0	>94.0	<10	<15

Note 1: For values of PTV dimension or volume not specified, linear interpolation between table entries is required.

Note 2: Protocol deviations greater than listed here as "minor" will be classified as "major" for protocol compliance (see Section 6.7).

RTOG 0813 (lung) and RTOG 0915 (lung) Table1

UC Treatment Planning Guidelines

- 9-15 coplanar/non-coplanar non-opposing static conformal beams (lung, liver, spine)
- Beams eye-view blocking with MLC at the isocenter with a margin of 0-2 mm (3DCRT)
- Rx isodose line = 66-90% (generally 80-90%)
- Single-segment “IMRT” optimization for select cases or FIF multiple fields
- VMAT (RapidArc) > 300 degree arc
  - 3-4 partial arcs (100 degree each)

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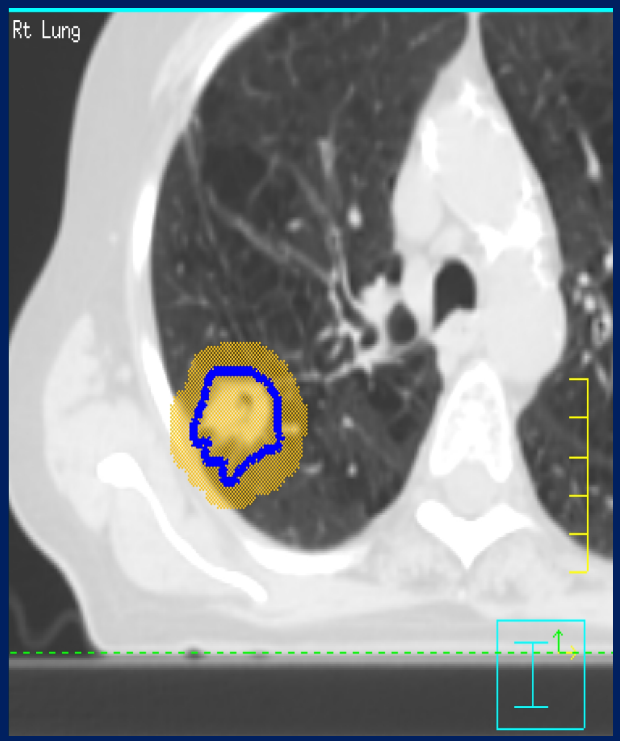
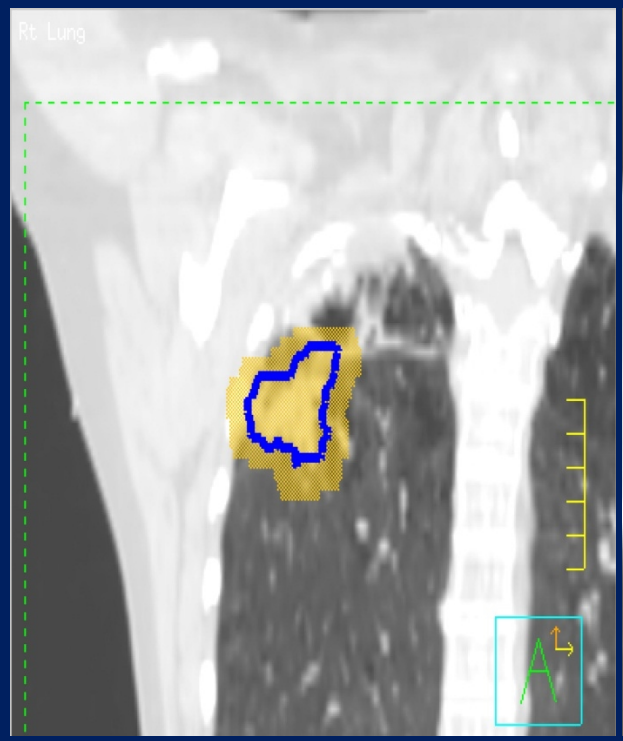
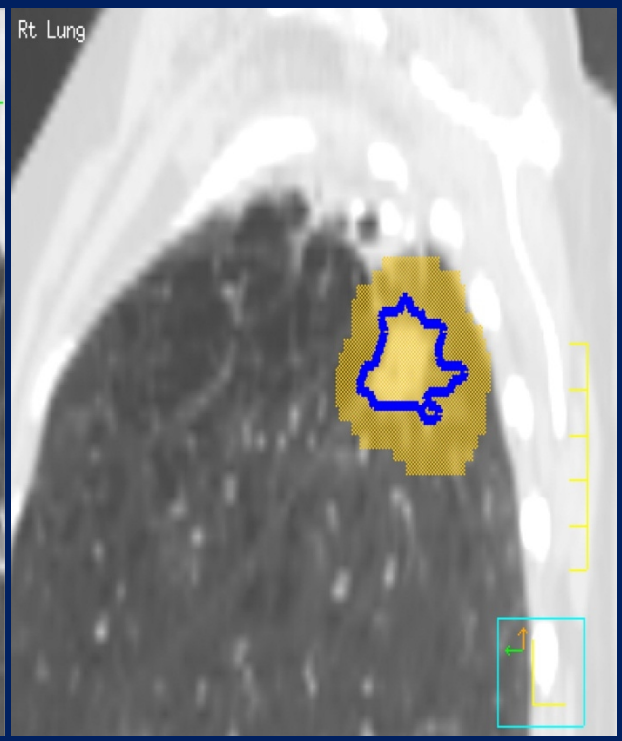
IMRT planning for Lung SBRT: 18Gy x 3







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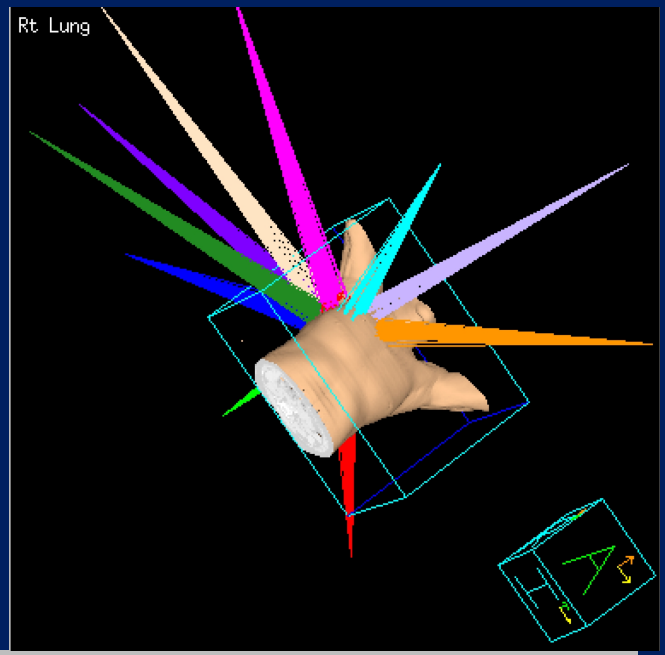
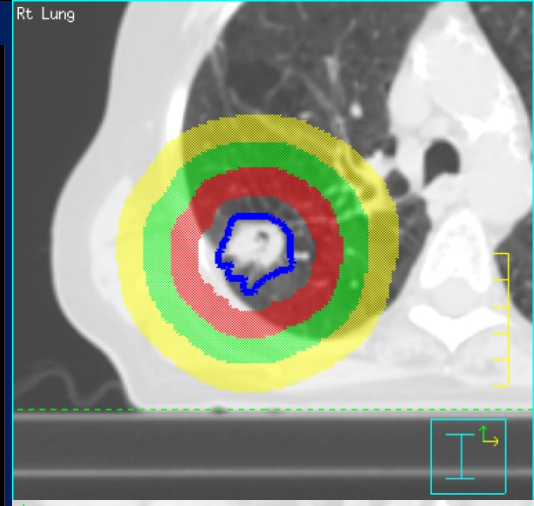
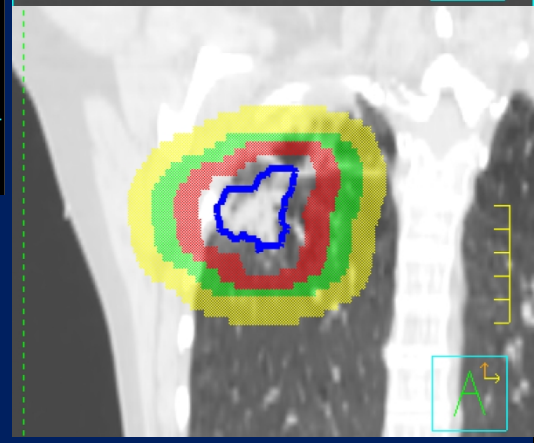
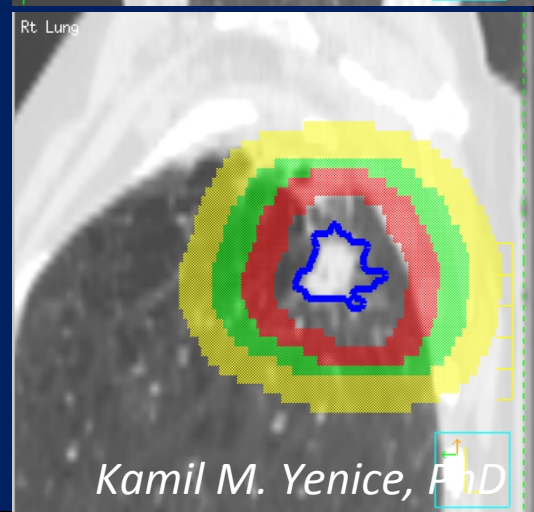
Beams Structures and Optimization

4D-CT Simulation
PTV = ITV + 5-7 mm margin









ROI	Type	Constrain	Target cGy	% Volume	% Variation	Weight	Objective Value
PTV	Min Dose		5400			20	0.0009294
PTV ring 1	Max Dose		5401			1.5	0.0002785
PTV ring 1	Max DVH		3780	50		1	6.0859e-05
PTV ring 2	Max DVH		2160	50		1	0.0001175
PTV ring 3	Max Dose		2600			1	0.0005041
bronchus spare	Max Dose		3000			1	0.000660113

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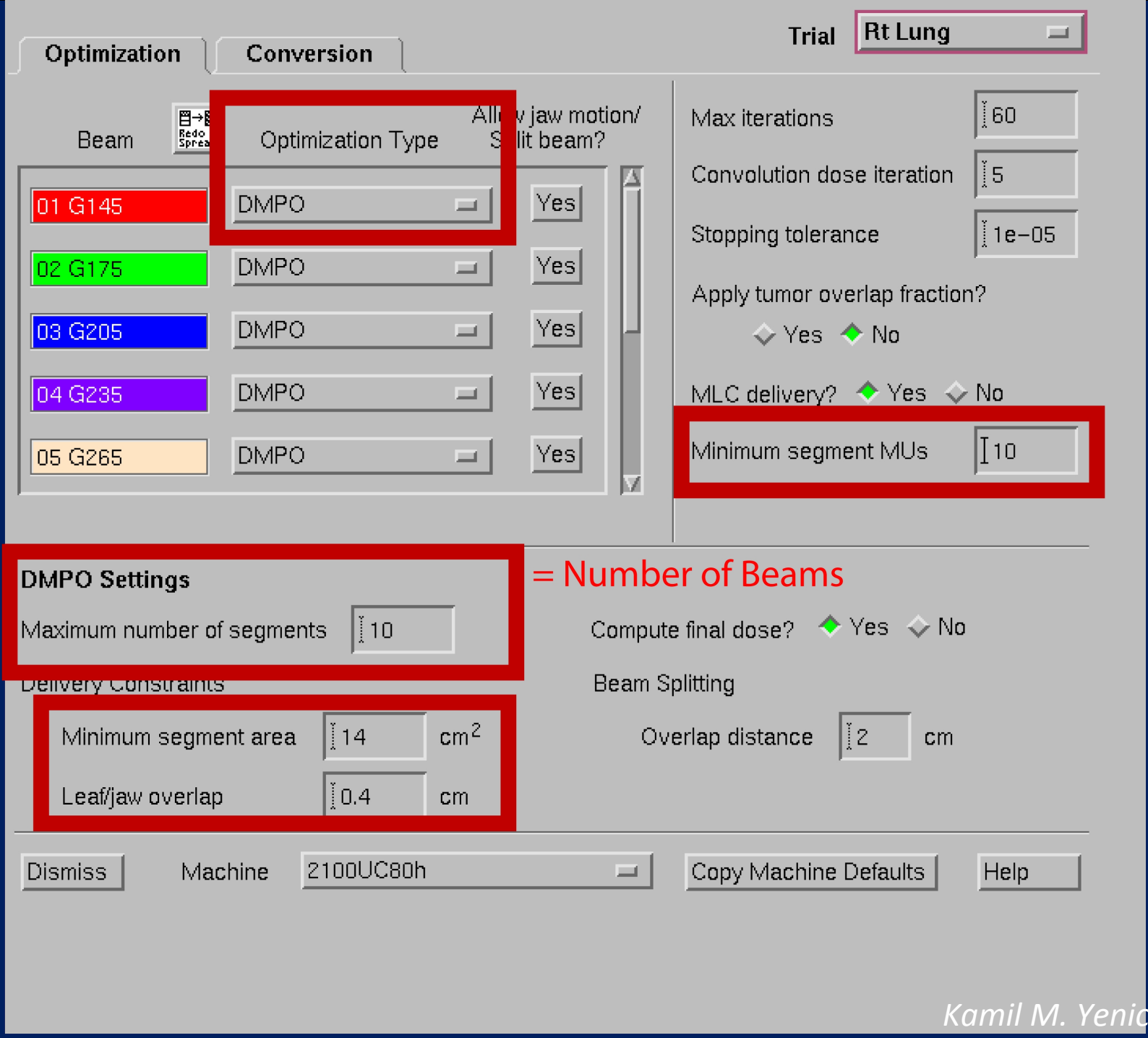

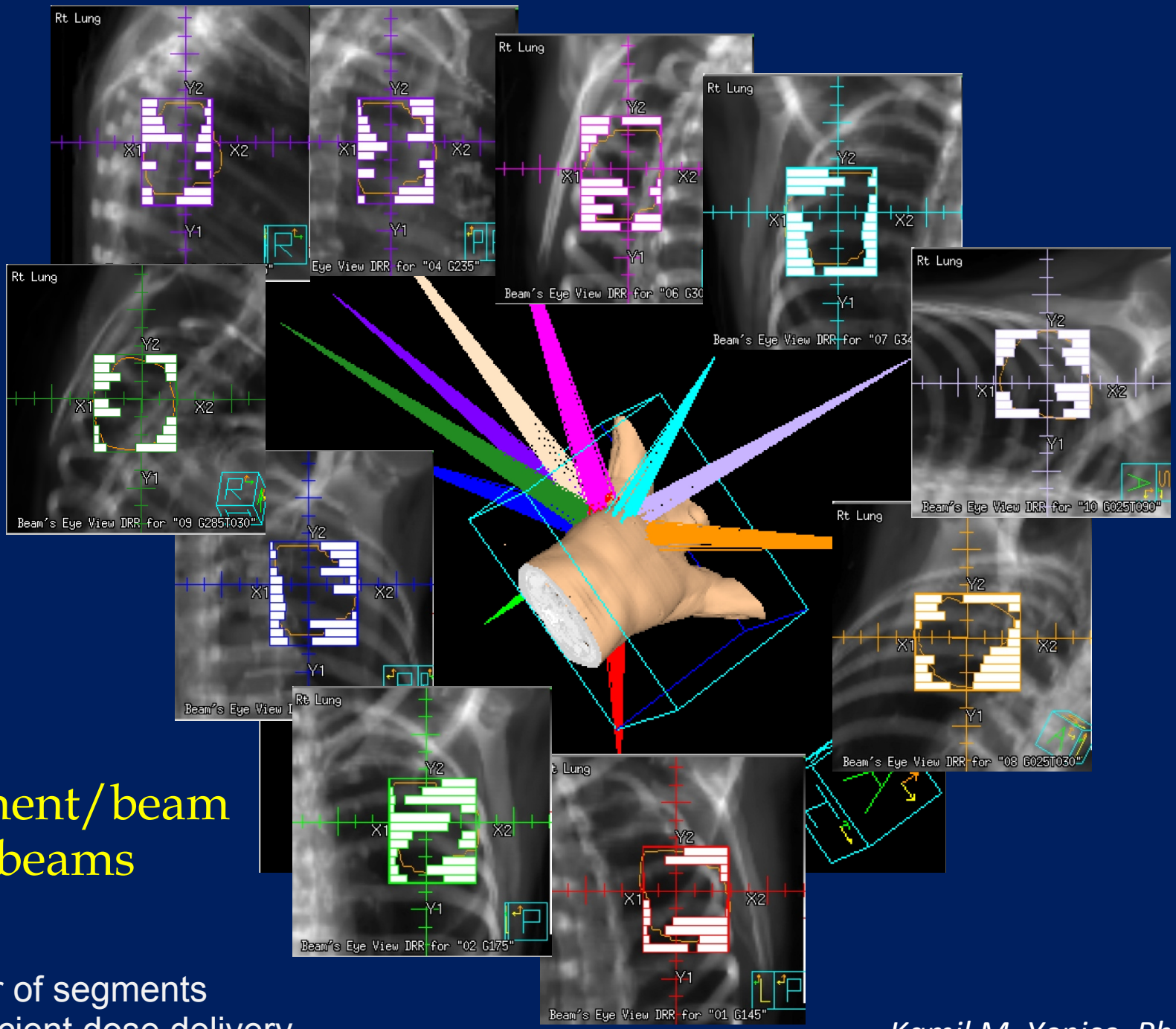

1 Segment/beam for all beams

Low number of segments
for more efficient dose delivery

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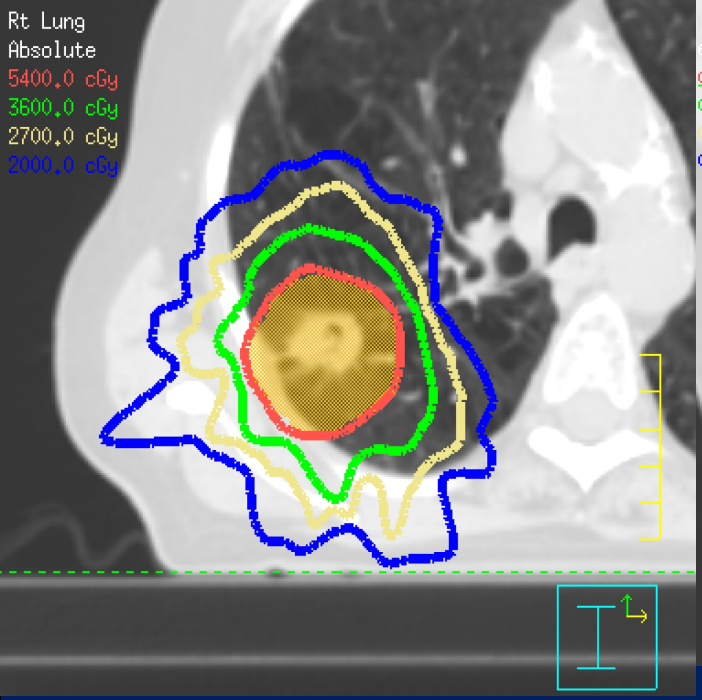
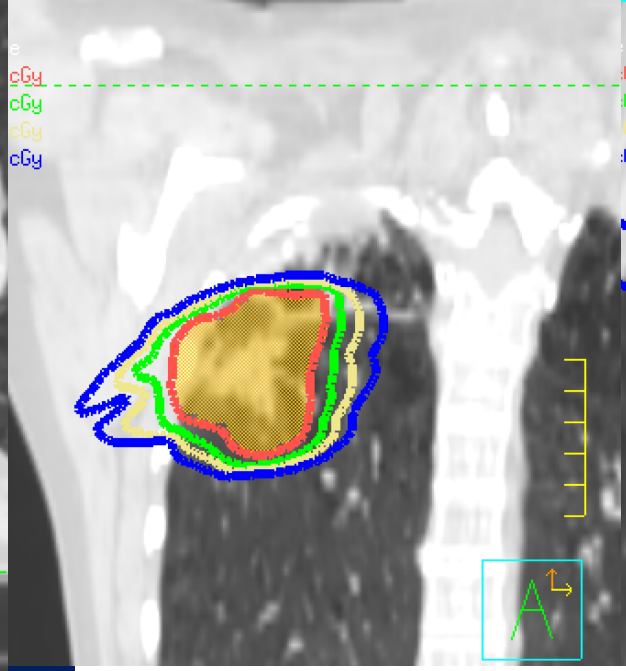
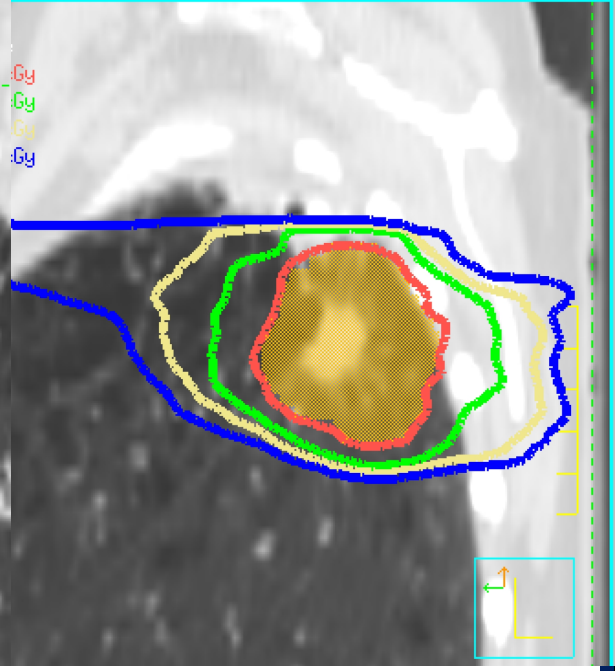
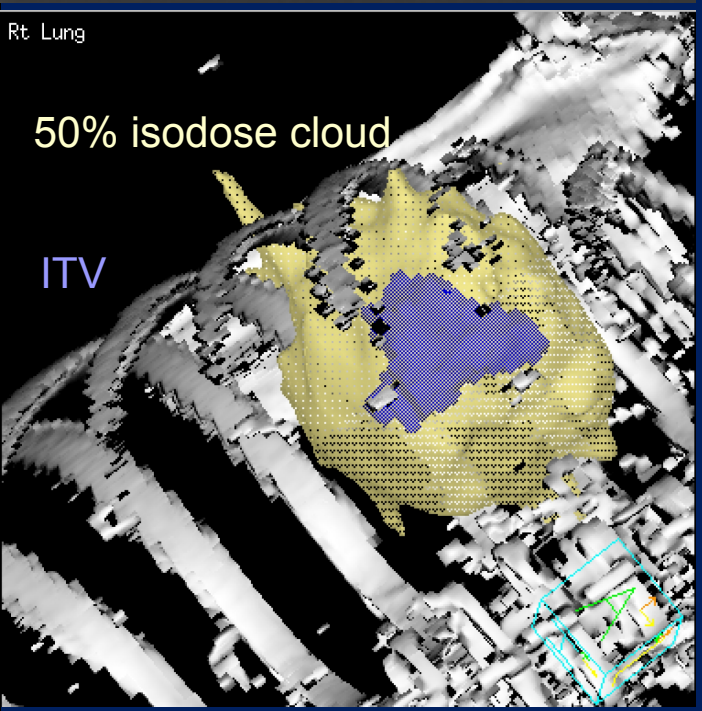
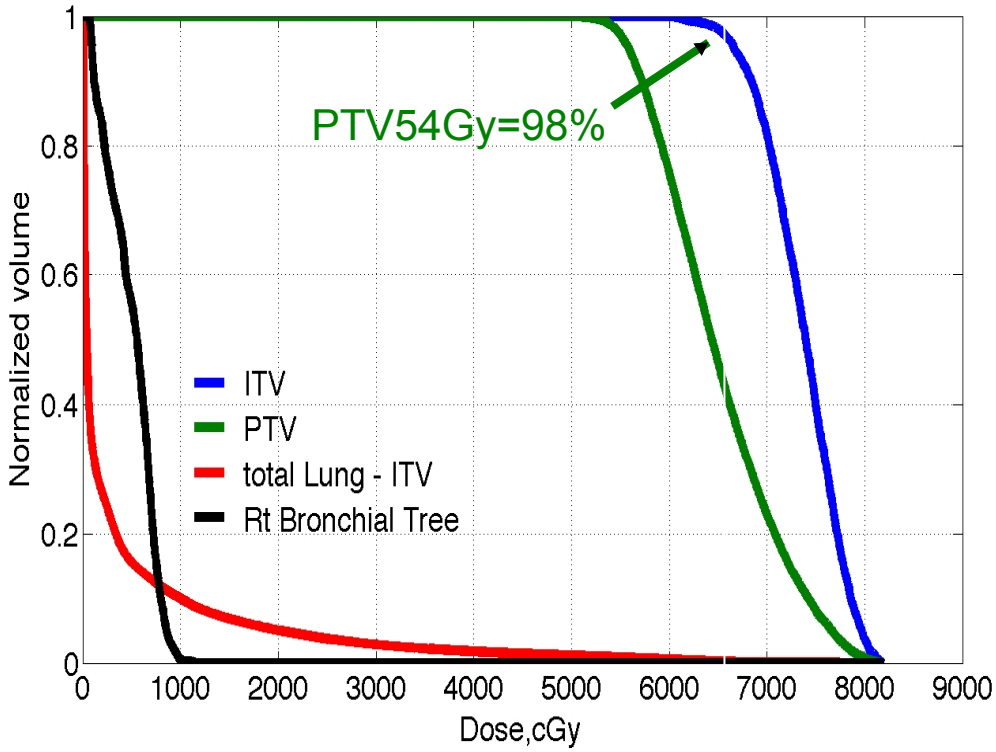

Rt Lung
Absolute
5400.0 cGy
3600.0 cGy
2700.0 cGy
2000.0 cGy

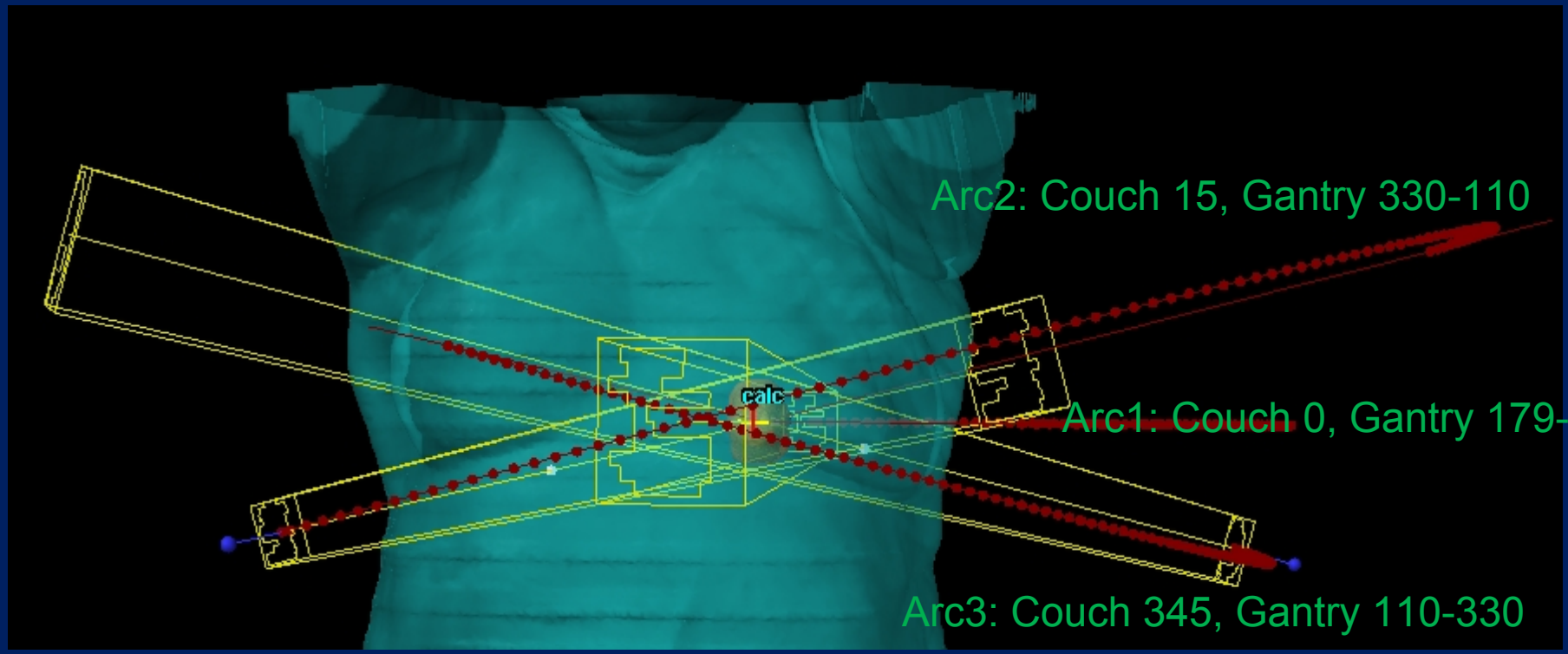

cGy
cGy
cGy


Gy
Gy
Gy
Gy


Rt Lung
50% isodose cloud
ITV


PTV54Gy=98%
Normalized volume
Dose,cGy
ITV
PTV
total Lung - ITV
Rt Bronchial Tree
0
0.2
0.4
0.6
0.8
1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

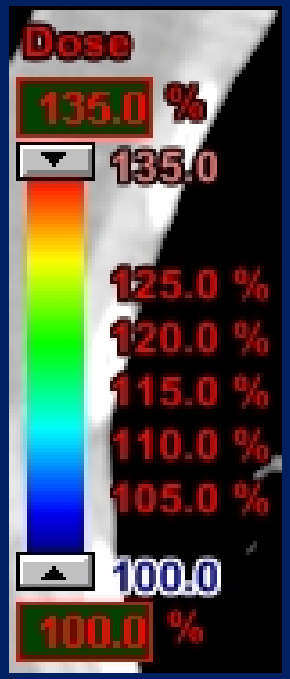
3-partial (100 deg) arc VMAT technique
Non-coplanar couch angle up to 20 degree



Arc 2 and Arc 3 are mostly anterior arcs to gain clearance

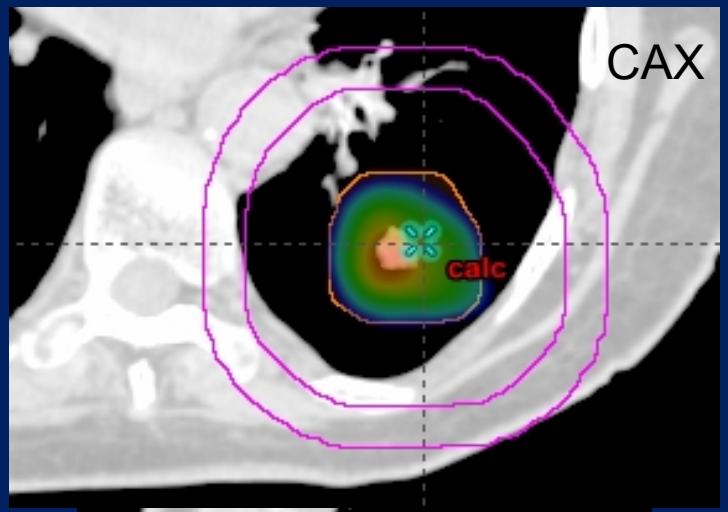
Slide: Courtesy of Linda Hong, PhD MSKCC

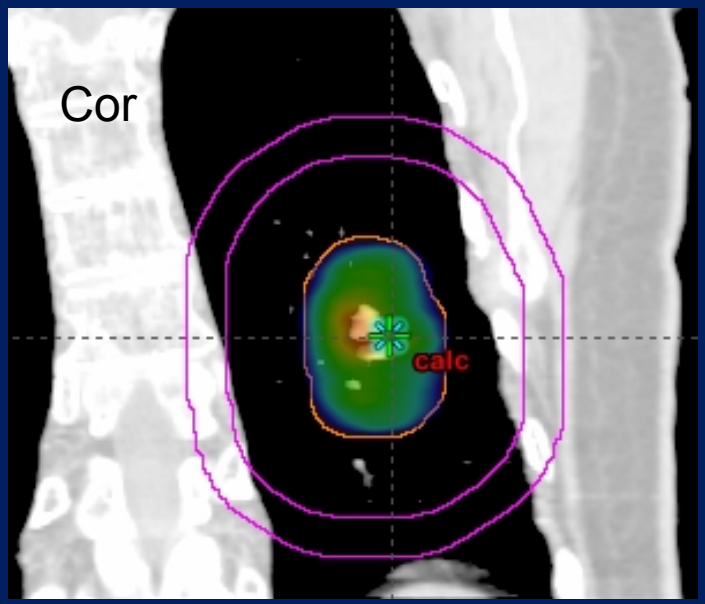
Prescription Isodose Surface Coverage

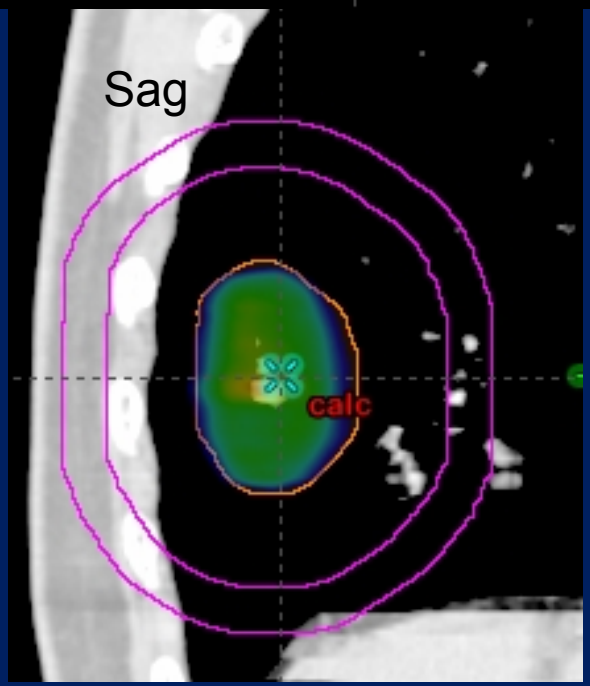


PD = 100% = 20 Gy/fx x 3
PTV V100 = 95%
PTV V100 = 95%

100% PD and Above





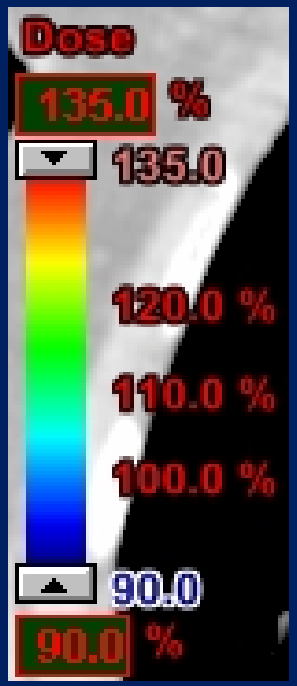


PTV

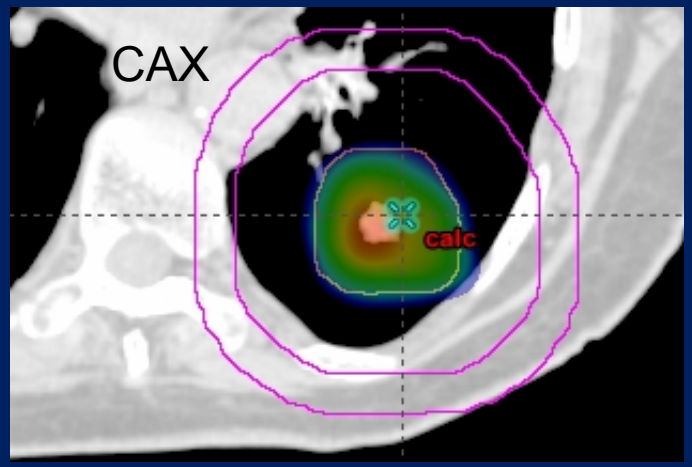
2cm-3cm ring

Slide: Courtesy of Linda Hong, PhD MSKCC

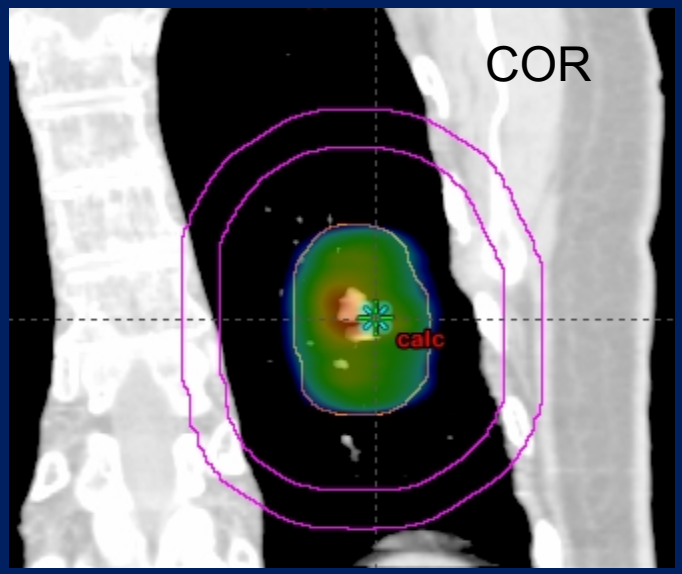
Prescription Isodose Surface Coverage

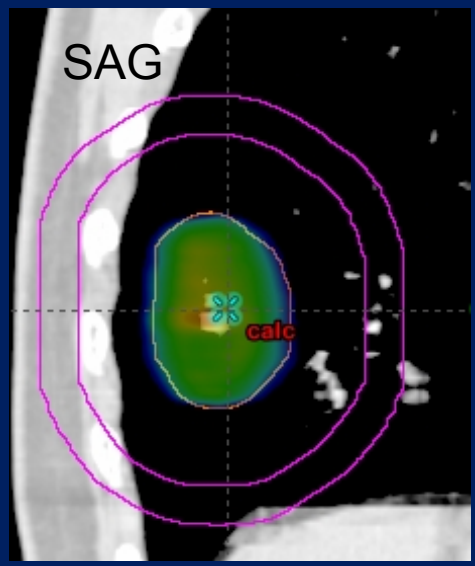


PD = 100% = 20 Gy/fx x 3
PTV V90% > 99%
Here PTV V90% = 100%



90% PD and Above



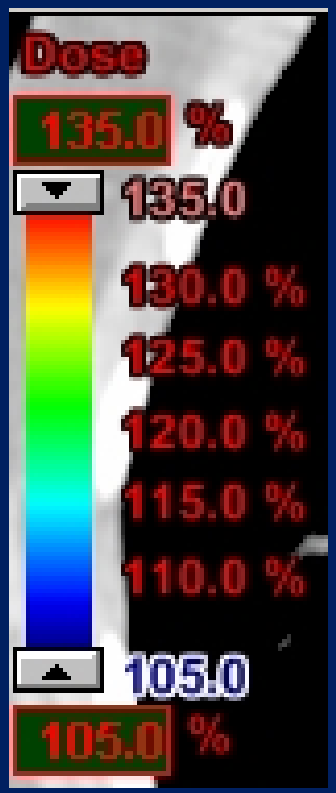


PTV

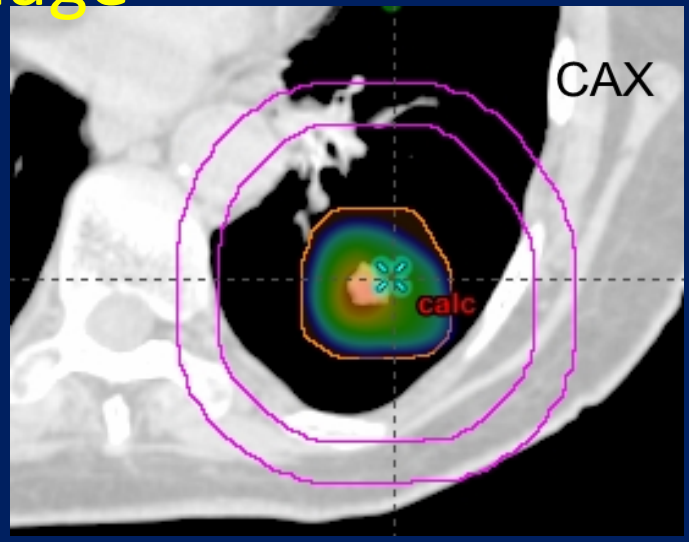
2cm-3cm ring

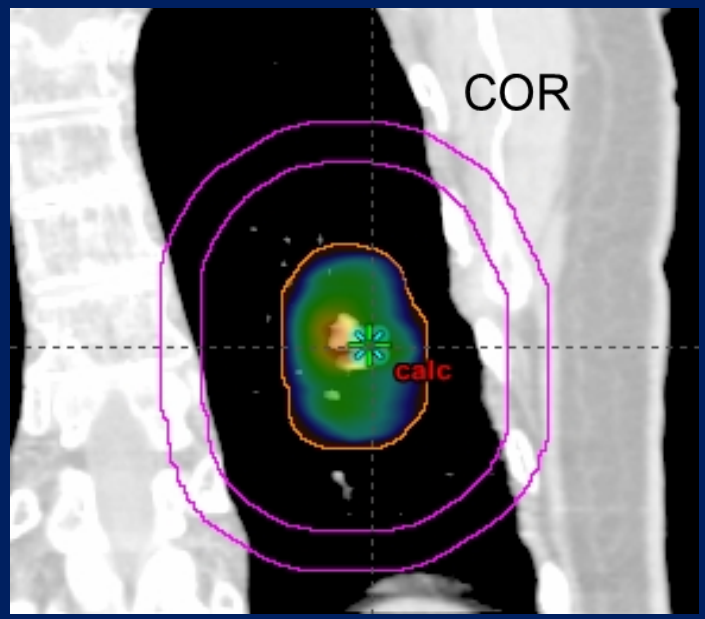
Slide: Courtesy of Linda Hong, PhD MSKCC

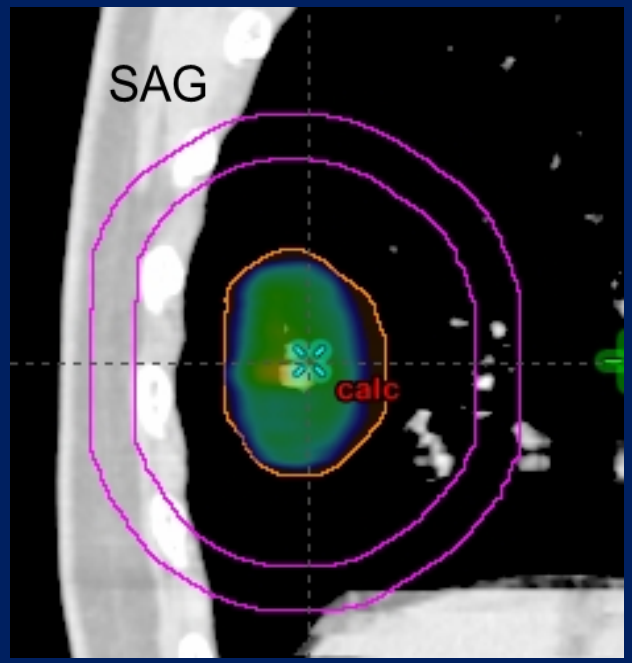
High Dose Spillage



PD = 100% = 20 Gy/fx x 3
Max PTV dose = 135.0%
105% covered volumes
outside of PTV <=
15% of volume of PTV
Here PTV = 40.2 cc
V105-PTV = 0.1 cc (0.2 %)







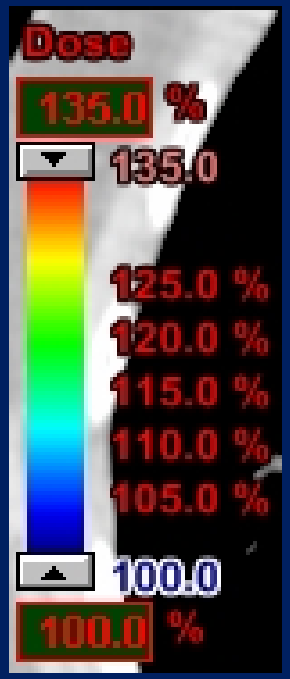
PTV

2cm-3cm ring

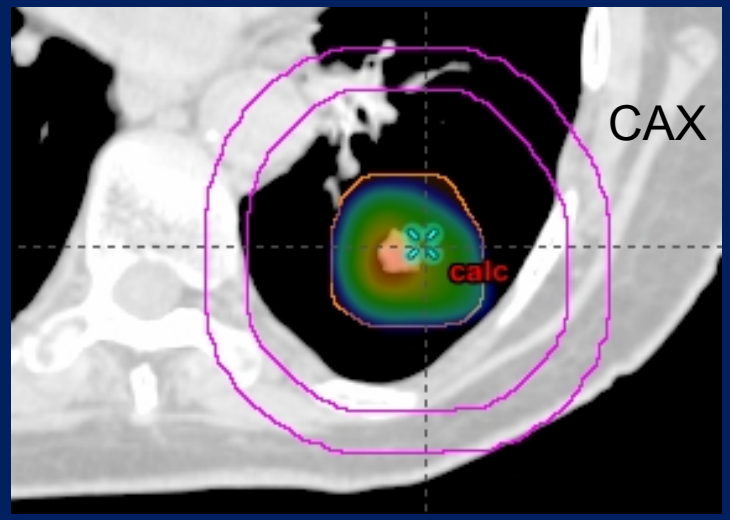
105% PD and Above

Slide: Courtesy of Linda Hong, PhD MSKCC

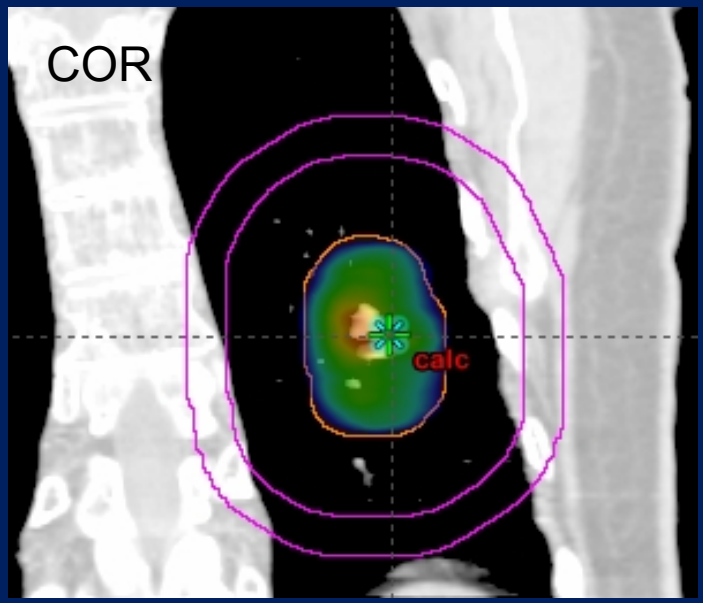
Conformality : Prescription Dose Volume vs. PTV Volume

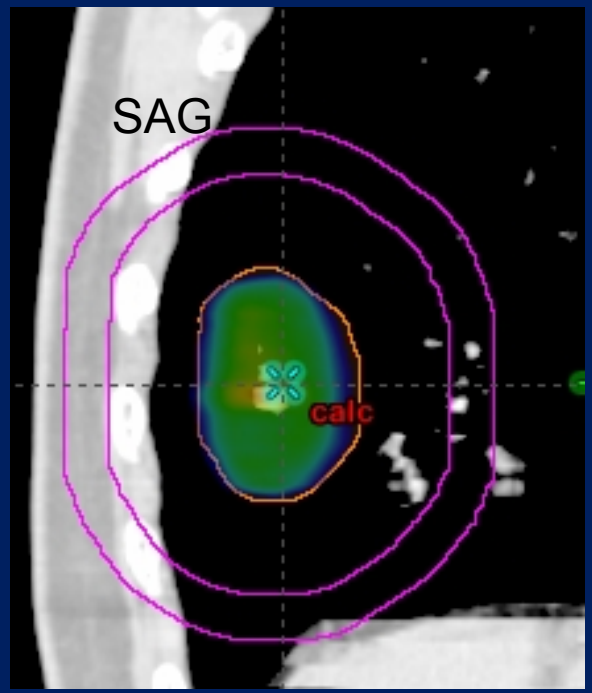


PD = 100% = 20 Gy/fx x 3
V100 / PTV volume <= 1.2
Here PTV = 40.2 cc
V100 = 41.0 cc
Ratio = 1.02



100% PD and Above





PTV

2cm-3cm ring

Slide: Courtesy of Linda Hong, PhD MSKCC

Intermediate Dose Spillage: $R_{50\%}$ and D_{2cm}

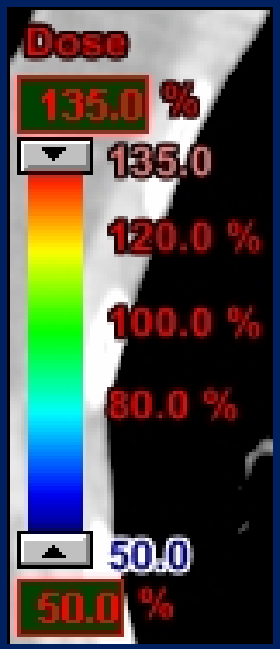
For PTV = 40.2 cc

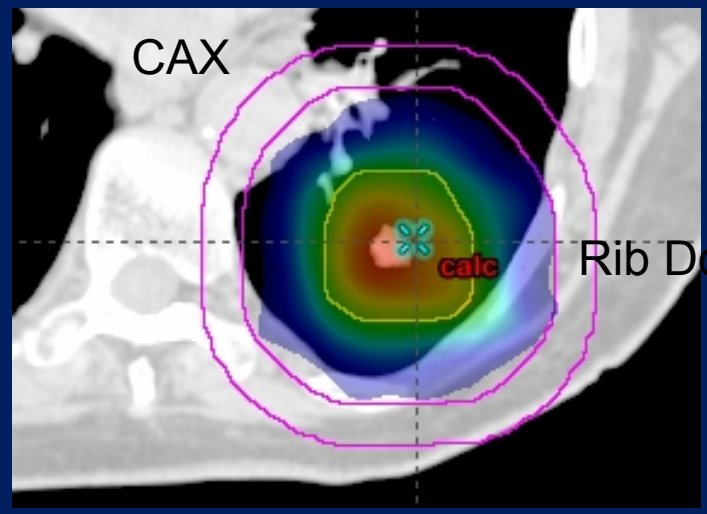
$R_{50\%}$ <= 4.2; D_{2cm} <= 59.6%

Here V50% = 169.5 cc

$R_{50\%}$ = 4.2

D_{2cm} = 52.6%

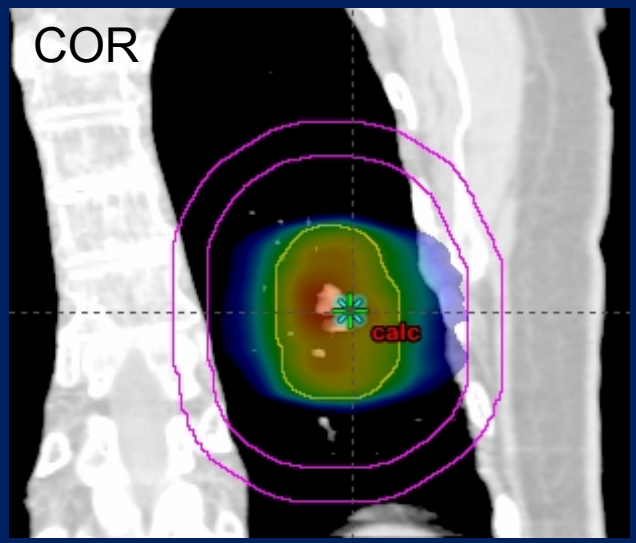


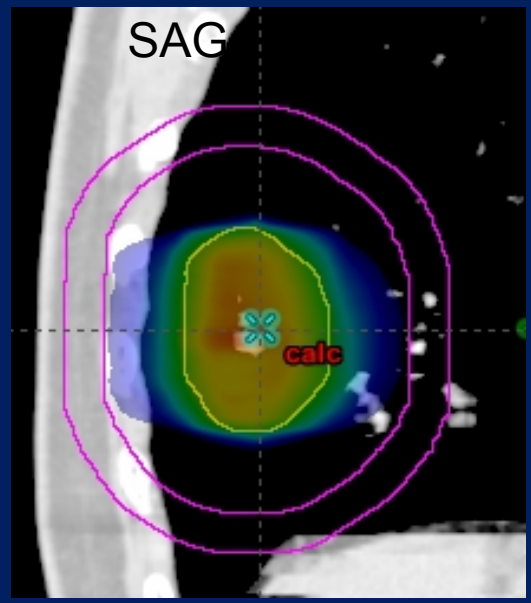


50% PD and Above

PTV

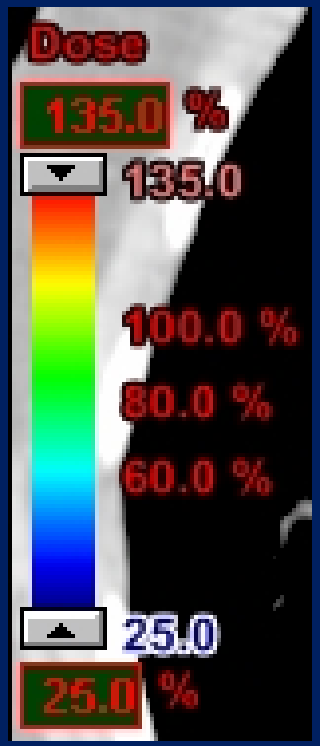
2cm-3cm ring





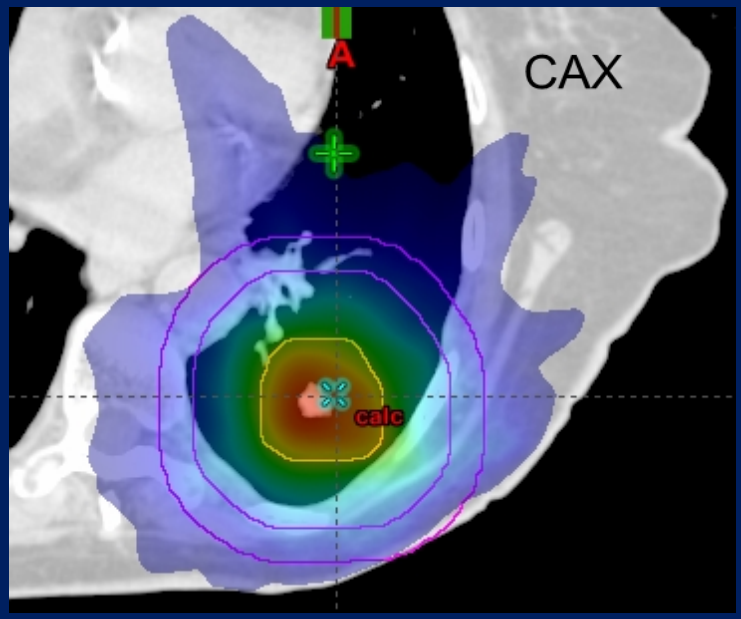
Dose falloff in 3D difficult without enough Non-coplanar beams/arcs due to lack of clearance

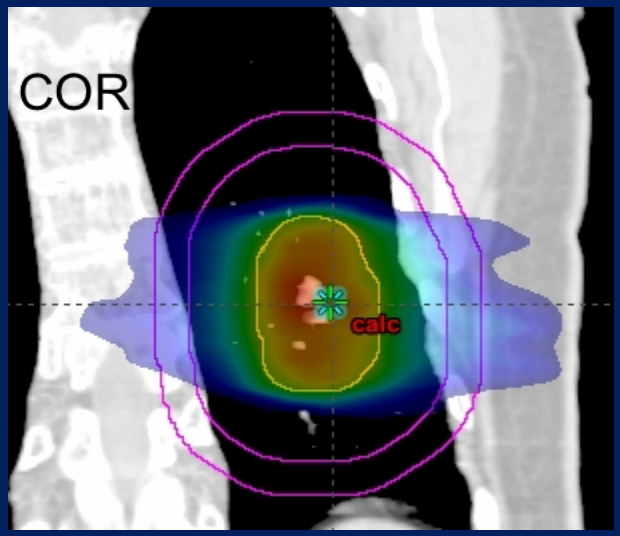
Slide: Courtesy of Linda Hong, PhD MSKCC

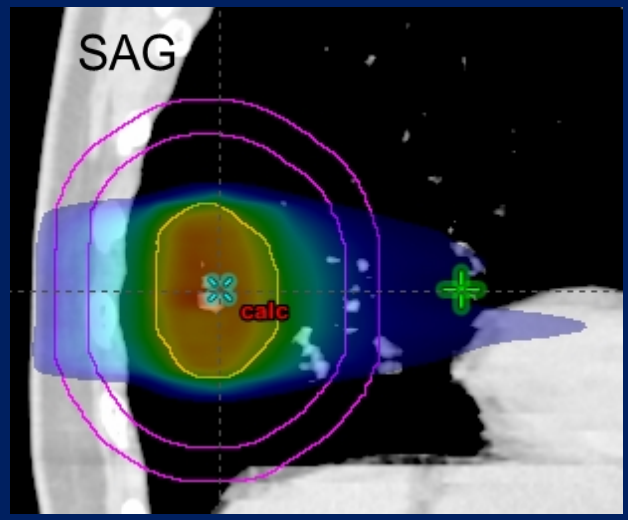


25% isodose restricted mainly in the ipsilateral lung

25% PD and Above





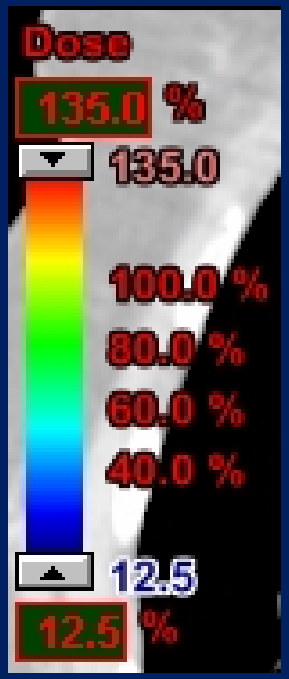


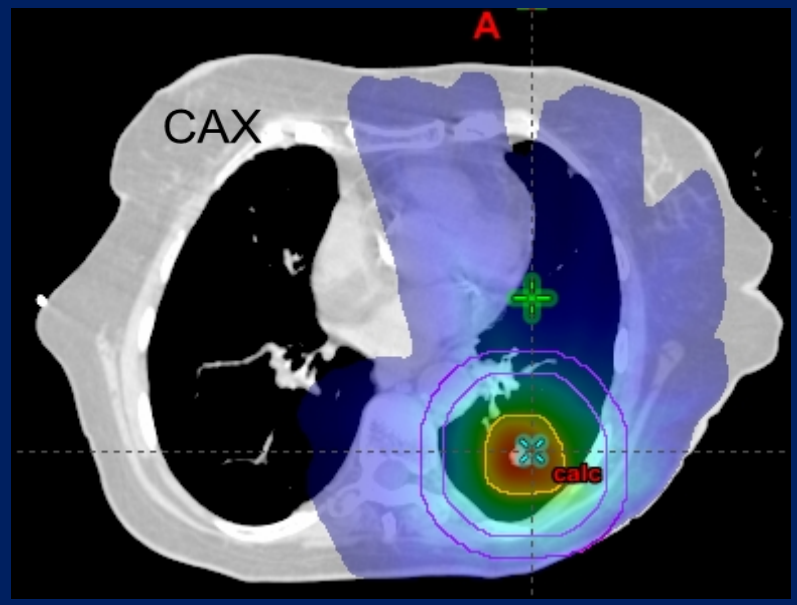
PTV

2cm-3cm ring

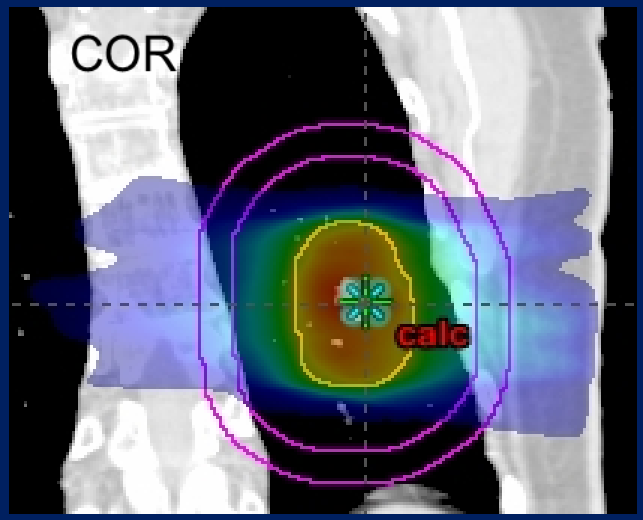
Slide: Courtesy of Linda Hong, PhD MSKCC

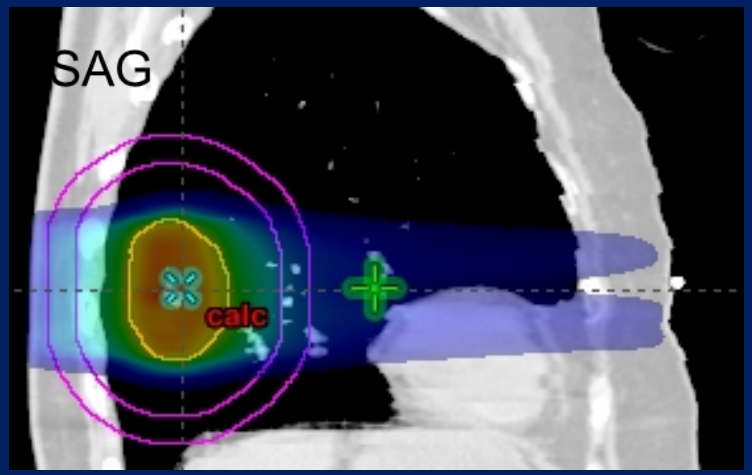
12.5% isodose restricted mainly in the ipsilateral lung





12.5% PD and Above



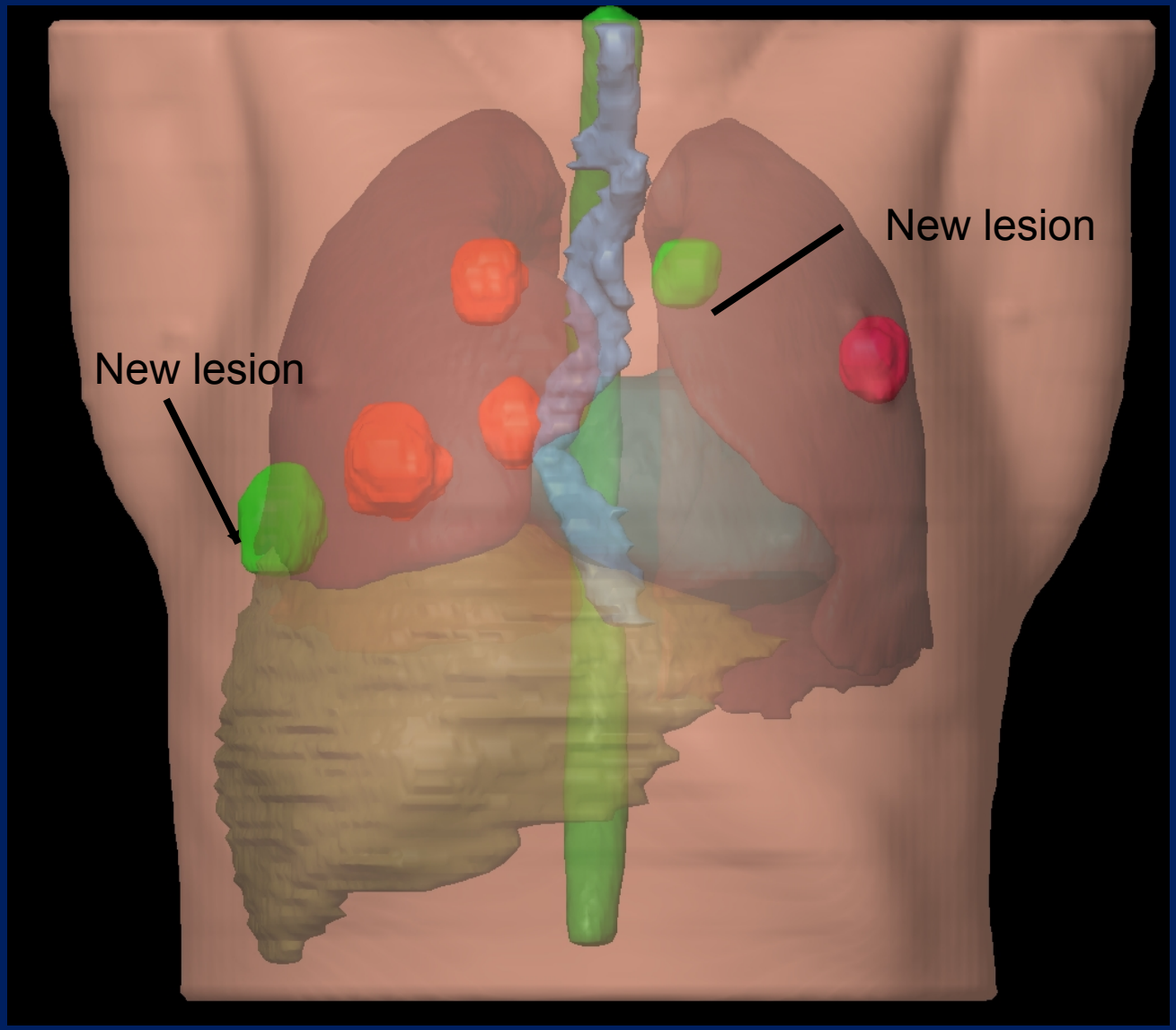


PTV

2cm-3cm ring

Slide: Courtesy of Linda Hong, PhD MSKCC

Multiple Lesions/Mets: More Challenging



Kamil M. Yenice, PhD

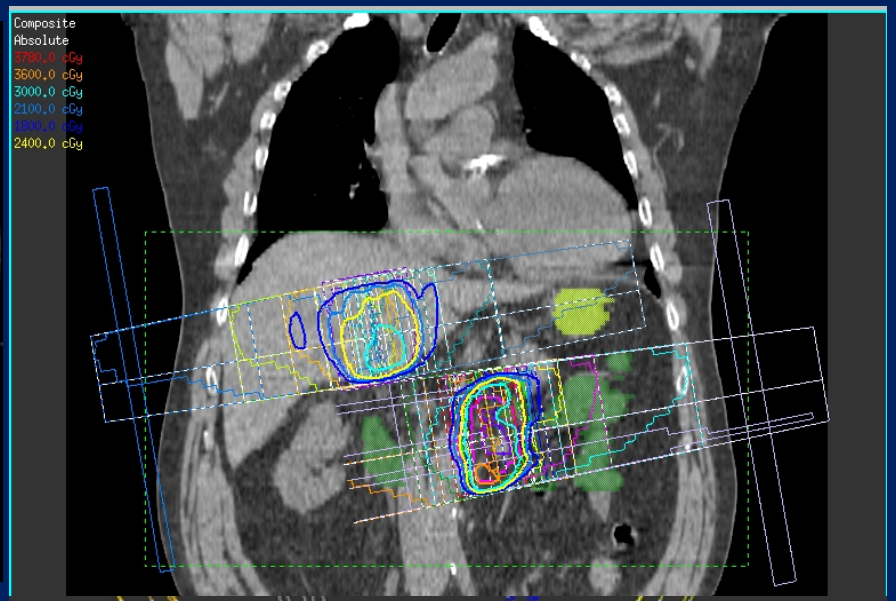
Patients with metastatic breast, adenocarcinoma of the prostate or non-small cell lung cancer with ≤ 4 metastases; all metastases not resected must be amenable to SBRT

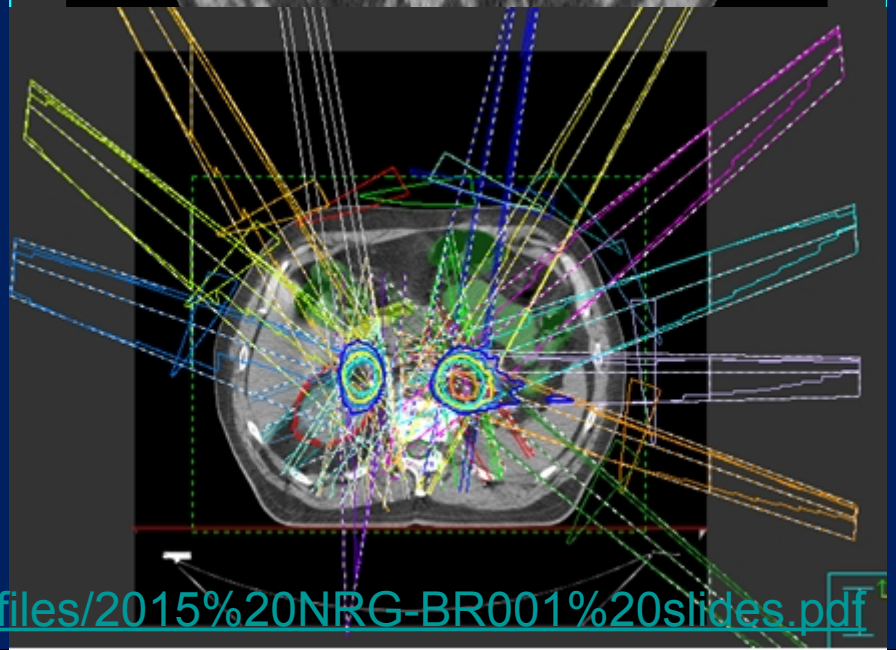
SBRT (in 3 or 5 fractions) to all existing metastases in 1-3 weeks

NRG BR001: A Phase I study of SBRT for the Treatment of Multiple Metastases

Prescription Doses		
Metastatic Locations	**Initial Starting Dose**	**Decreased DLT Dose**
Lung--Peripheral	45 Gy (3 fractions)	42 Gy (3 fractions)
Lung—Central	50 Gy (5 fractions)	47.5 Gy (5 fractions)
Mediastinal/Cervical Lymph Node	50 Gy (5 fractions)	47.5 Gy (5 fractions)
Liver	45 Gy (3 fractions)	42 Gy (3 fractions)
Spinal/Paraspinal	30 Gy (3 fractions)	27 Gy (3 fractions)
Osseous	30 Gy (3 fractions)	27 Gy (3 fractions)
Abdominal-pelvic metastases (lymph node/adrenal gland)	45 Gy (3 fractions)	42 Gy (3 fractions)

NRG BR001 protocol benchmark case





Metastatic Locations	Initial Starting Dose
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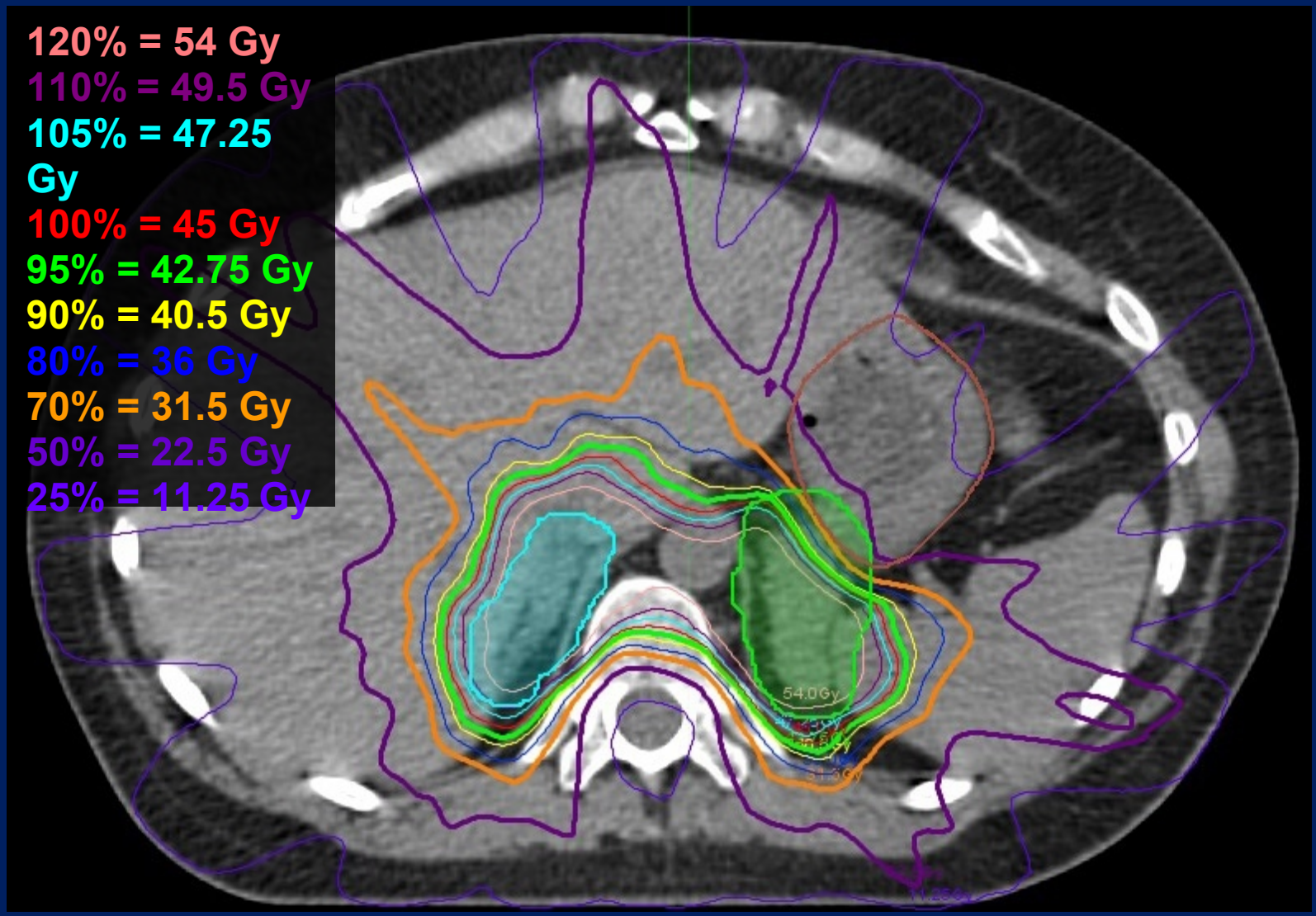
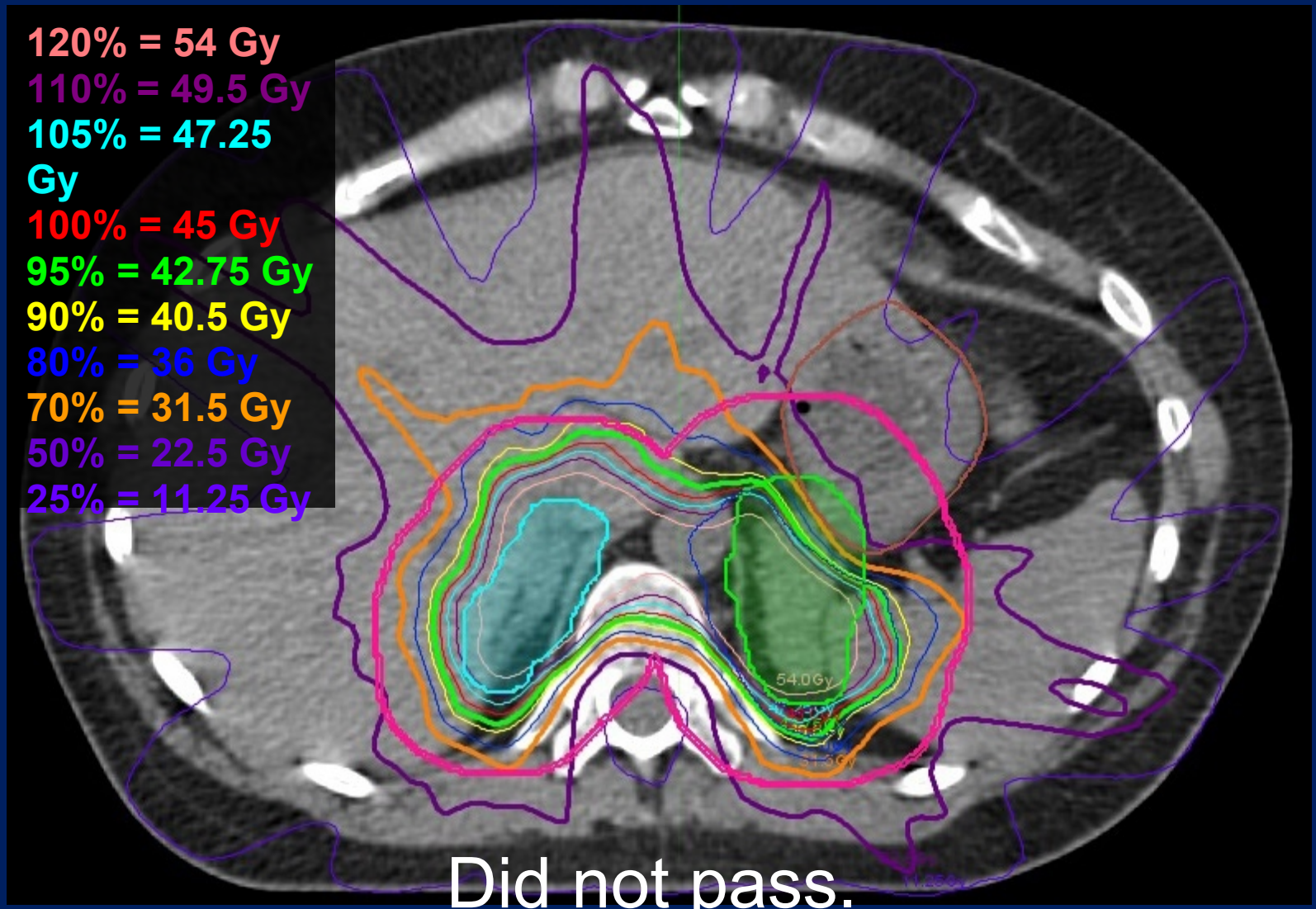
Mediastinal/Cervical Lymph Node	50 Gy (5 fractions)
Liver	45 Gy (3 fractions)
Spinal/Paraspinal	30 Gy (3 fractions)
Osseous	30 Gy (3 fractions)
Abdominal-pelvic metastases (lymph node/adrenal gland)	45 Gy (3 fractions)

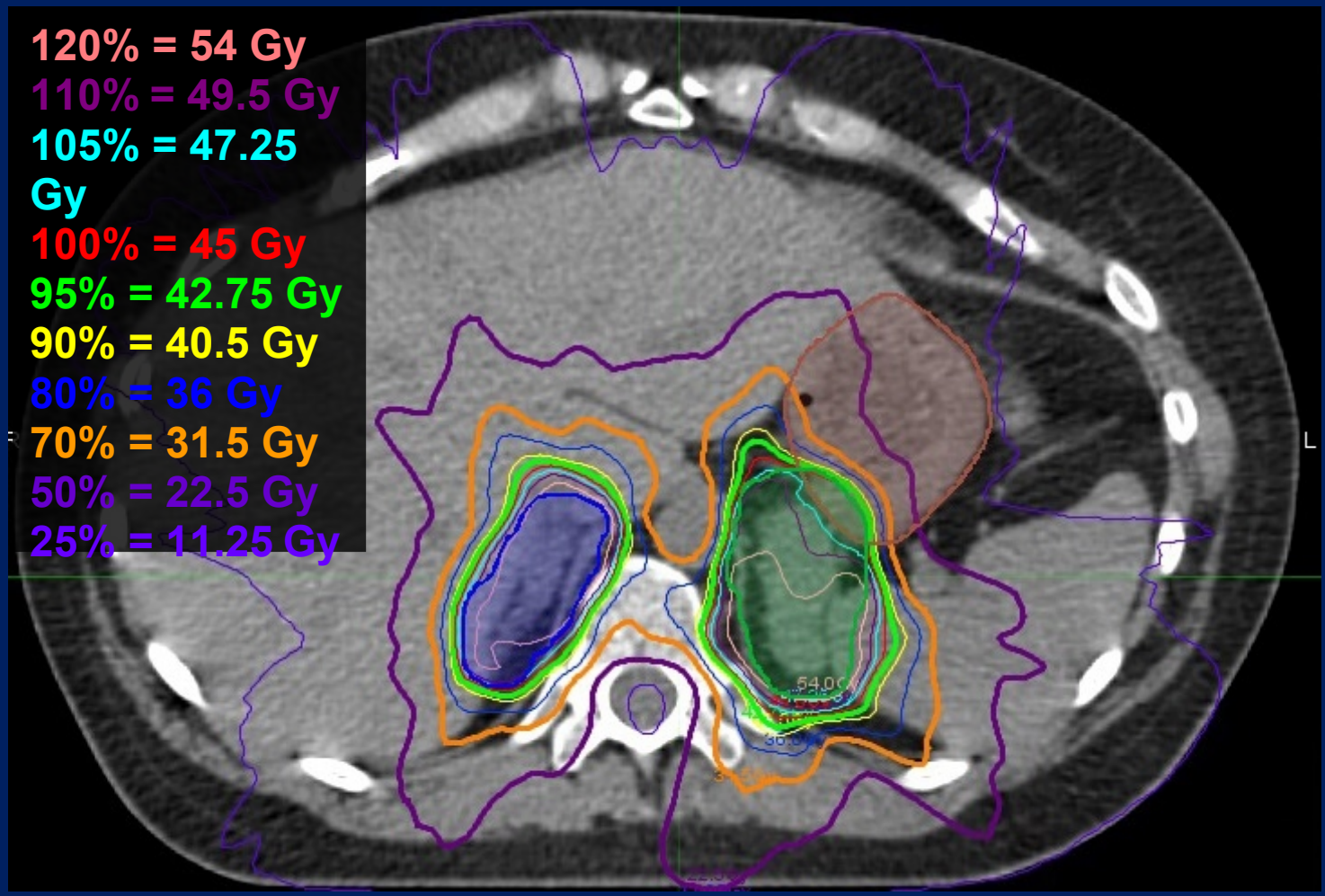
http://rpc.mdanderson.org/RPC/credentialing/files/2015%20NRG-BR001%20slides.pdf

Benchmark Case – did not pass

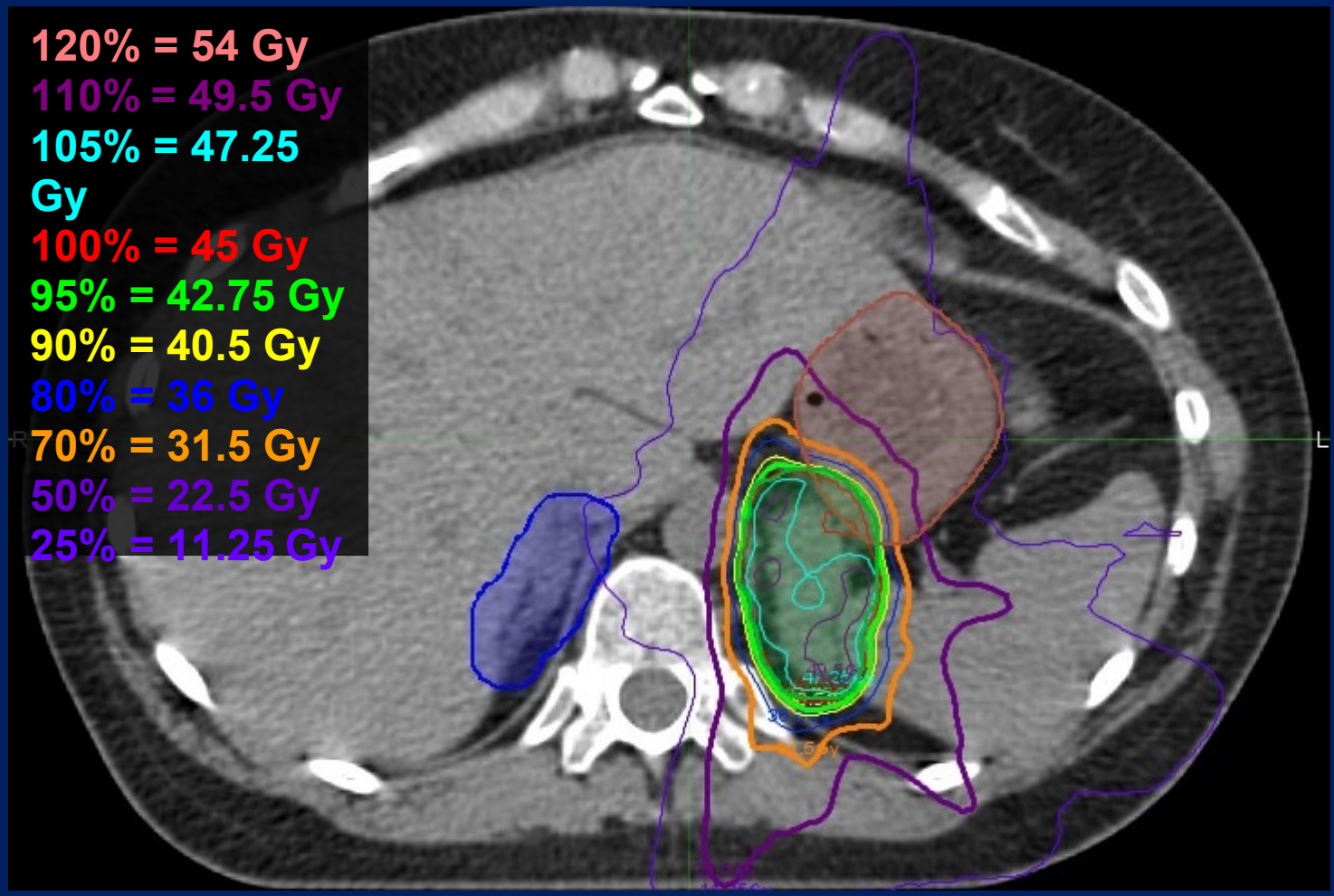



120% = 54 Gy
110% = 49.5 Gy
105% = 47.25 Gy
100% = 45 Gy
95% = 42.75 Gy
90% = 40.5 Gy
80% = 36 Gy
70% = 31.5 Gy
50% = 22.5 Gy
25% = 11.25 Gy
54.0Gy

Did not pass.



Passed on 2nd Try.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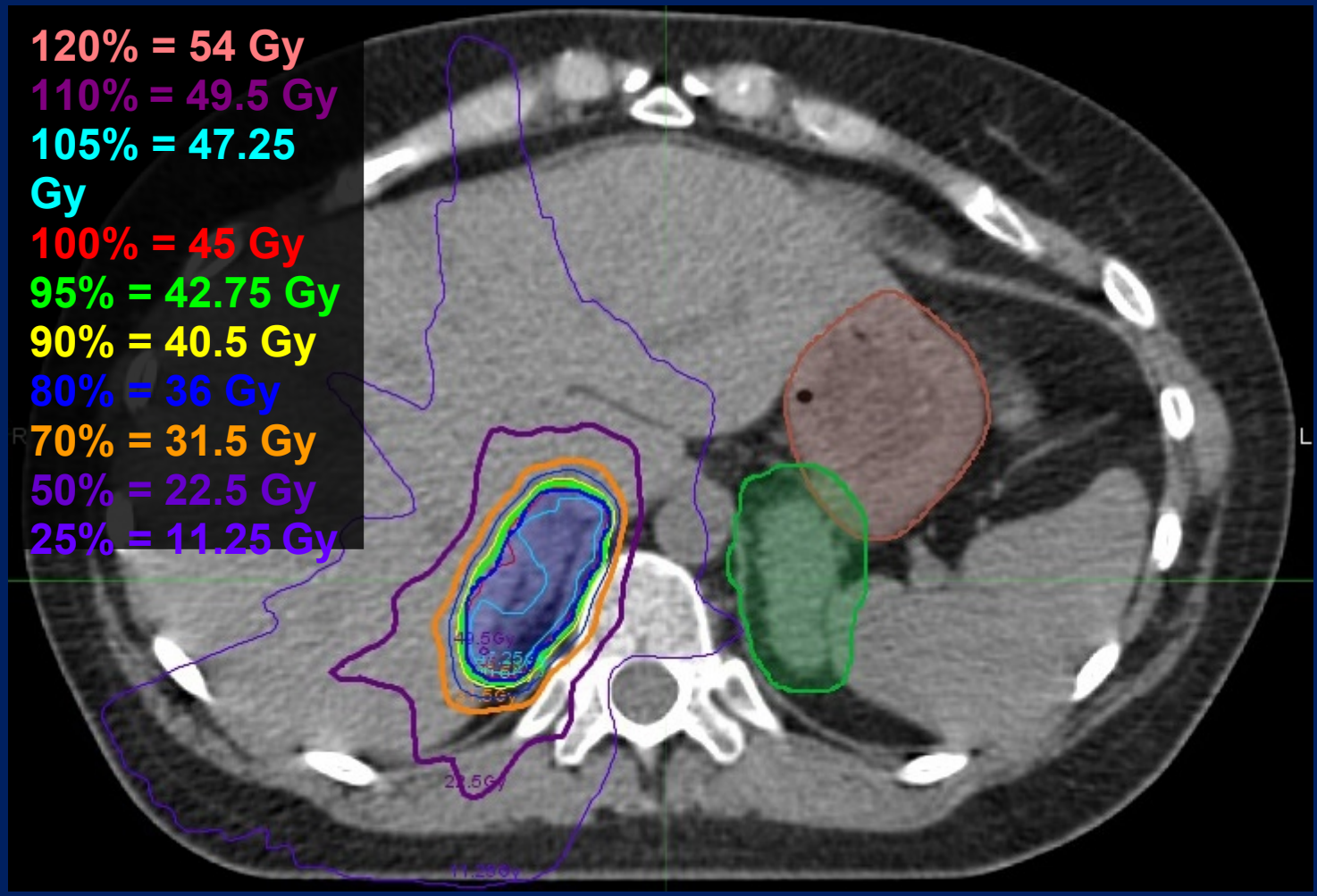
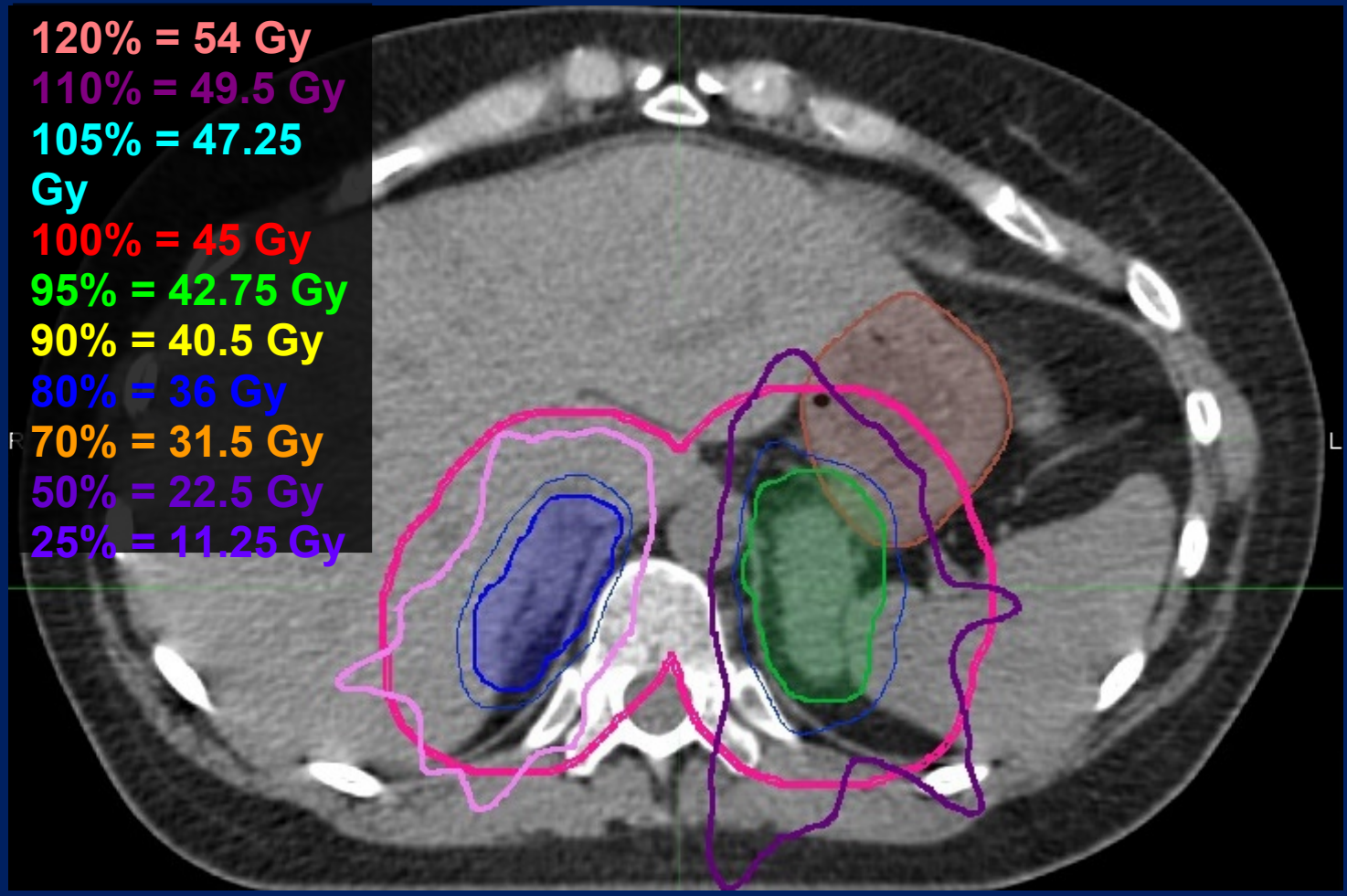
70% = 31.5 Gy
50% = 22.5 Gy
25% = 11.25 Gy

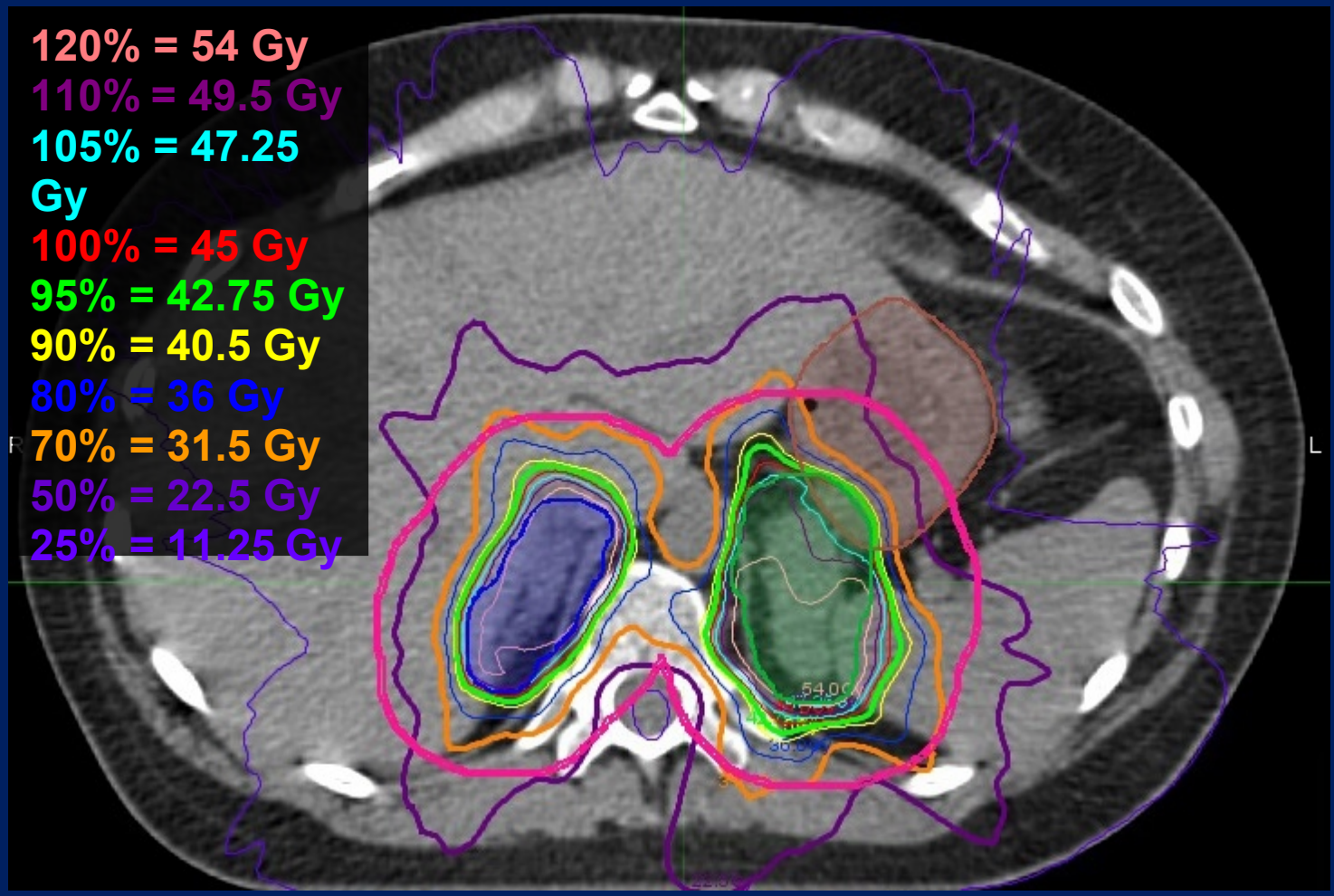
NRG BR001: Benchmark Case



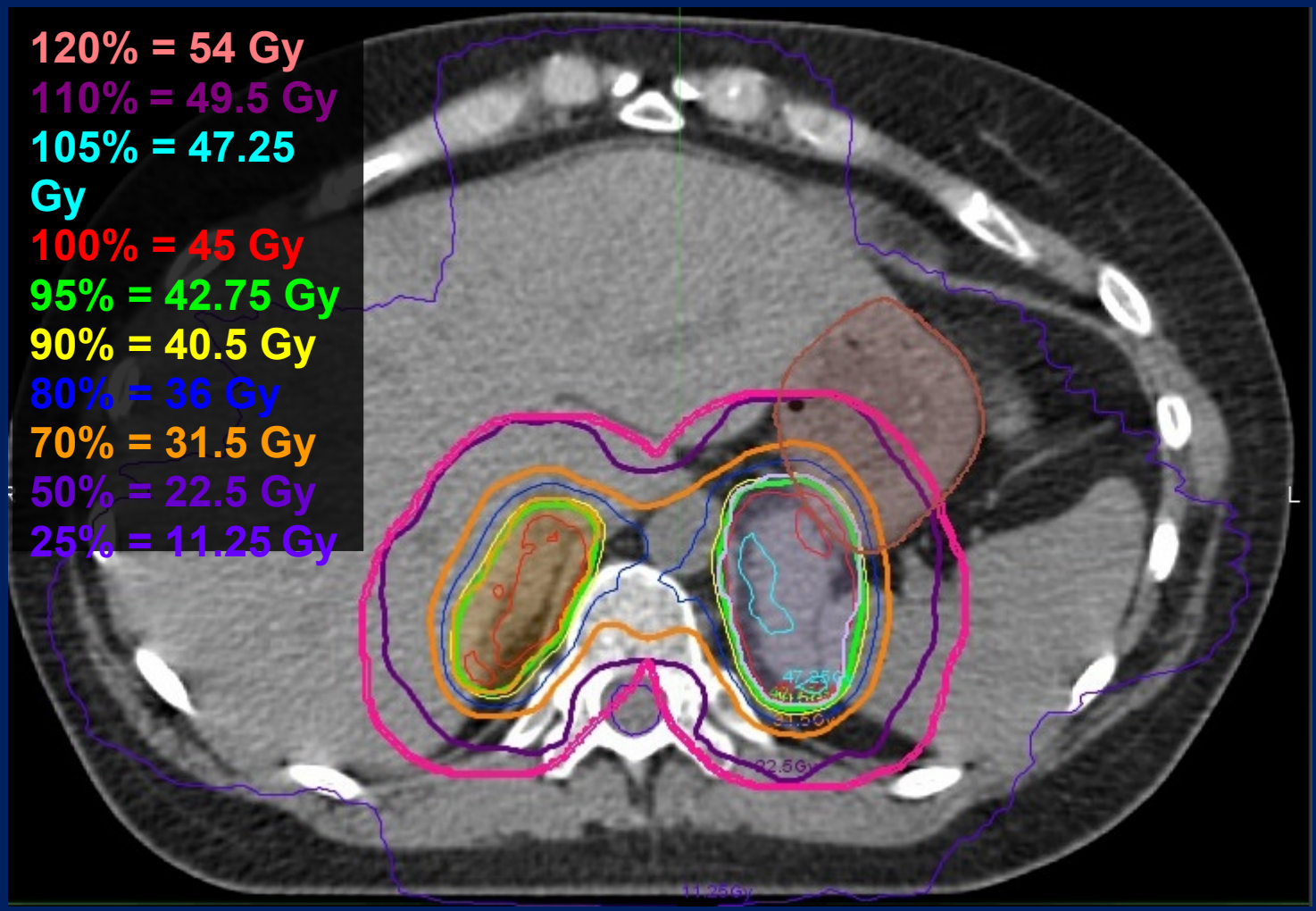
NRG BR001: Benchmark Case



NRG BR001: Benchmark Case

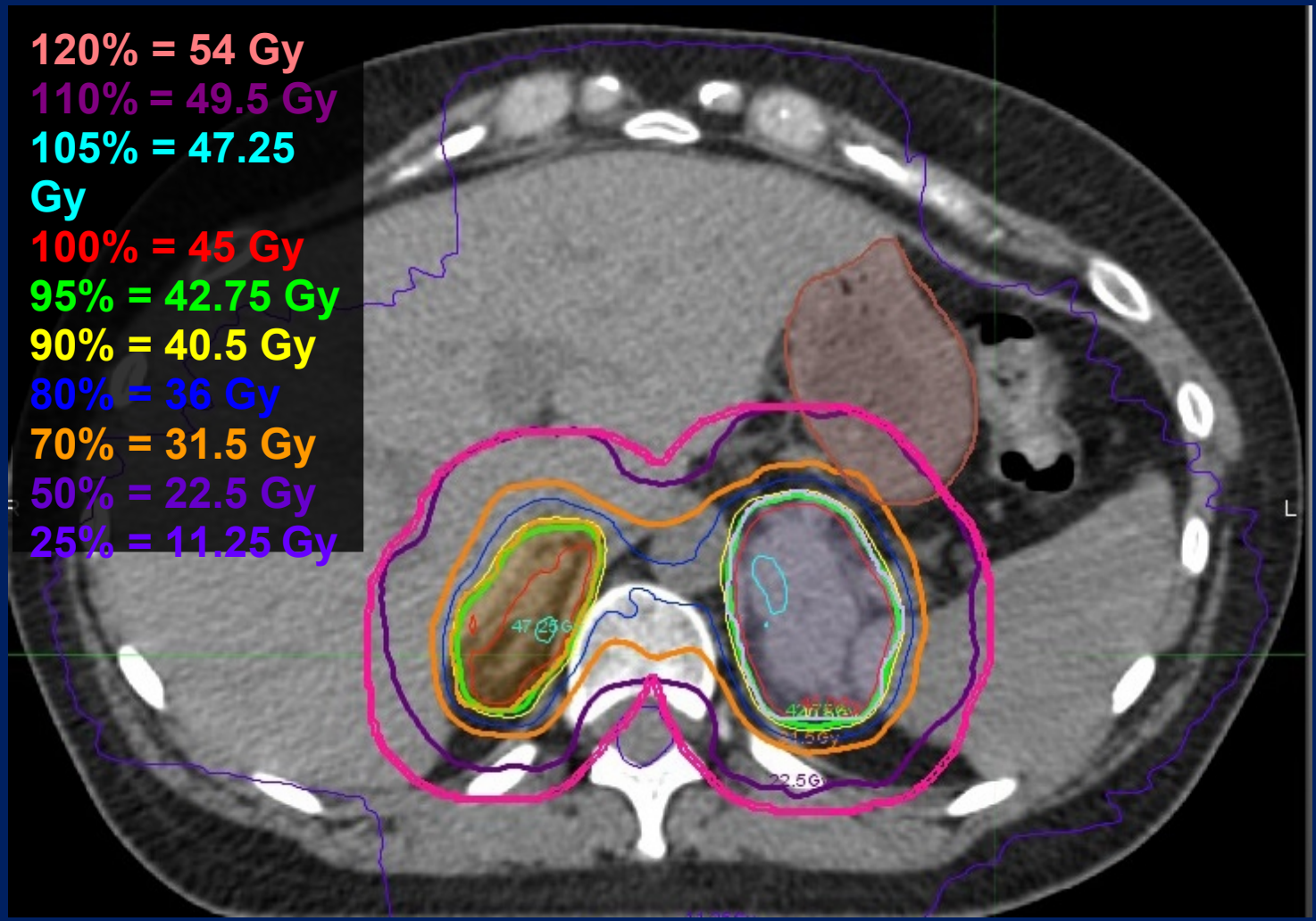


NRG BR001: Benchmark Case



Passed on 1st try using VMAT.

NRG BR001: Benchmark Case



Passed on 1st try using VMAT.

NRG BR001: Minimum IGRT requirements for SBRT

Metastatic Location	Minimum IGRT Requirement	
	No Fiducials	**With Fiducials****
Lung--Peripheral+	Volumetric (3D)	Orthogonal kV (2D)
Lung—Central+	Volumetric (3D)	Orthogonal kV (2D)
Mediastinal/Cervical LN	Volumetric (3D)	N/A
Liver+	Volumetric (3D)	Orthogonal kV (2D)
Spinal	Orthogonal kV (2D)	Orthogonal kV (2D)
Osseous*	Orthogonal kV (2D)	N/A
Abdominal-pelvic+	Volumetric (3D)	Orthogonal kV (2D)

***NOTE**: When osseous/rib metastases are classified into another metastatic location, follow the IGRT guidelines for that site.

****NOTE**: When a metastasis contains an implanted fiducial that is clearly visible on kV orthogonal or volumetric imaging, either method can be used

+NOTE: Registration using a soft tissue surrogate for the tumor is recommended for lung, liver, and abdominal-pelvic metastases for both 3D and 2D IGRT datasets.

Image-Guidance: Treatment Verification

- Pre-treatment verification: 3D
  - Daily kV- setup to to bones or implanted fiducials
  - CBCT- daily if ≤ 5 fractions
- On-board kV/MV imaging: 2D
  - Daily kV- setup to to bones or implanted fiducials
  - Orthogonal and portal verification gated images, fluoroscopic imaging
- Mid and post procedure imaging
  - Evaluation of intrafraction patient/target motion

AP View

Under fluoro: only the MLC shape outline conforming to GTV
When the MLC outline turns green, beam is ON (Gated delivery).
GTV is visible on screen when fluoro is on.
Our goal is for GTV to match MLC shape when beam is ON.

Slide: Courtesy of Linda Hong, PhD MSKCC

AP View

AP View

After 5mm superior adjustment.

GTV is 5mm too inferior (MLC acts as a scale). CBCT was done with free breathing (non-gated), therapist did not align superior part of CBCT with Gated CTsim tumor during image fusion.

Oblique View

A different beam angle verification

Slide and images: Courtesy of Linda Hong, PhD MSKCC

Summary

- SBRT requires multi-disciplinary team approach
- Clinical experience with conventional radiotherapy does not extrapolate to SBRT
- RTOG/NRG protocols provide useful guidelines for SBRT treatment planning
- Establishing clear guidelines and team approach in your own institution are necessary for the safe delivery of SBRT.
- Verification of each step in the SBRT treatment process is a must

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Acknowledgement

Karl Farrey, MS

Julien Partouche, MS

Tianming Wu, PhD

Linda Hong, PhD (MSKCC)

Hania Al-Hallaq, PhD

Kamil M. Yenice, PhD