Stereotactic Body Radiation Therapy (SBRT)

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Disclosure Information

Peter Balter, Ph.D.

I have the following financial relationships to disclose

Grant or research support from

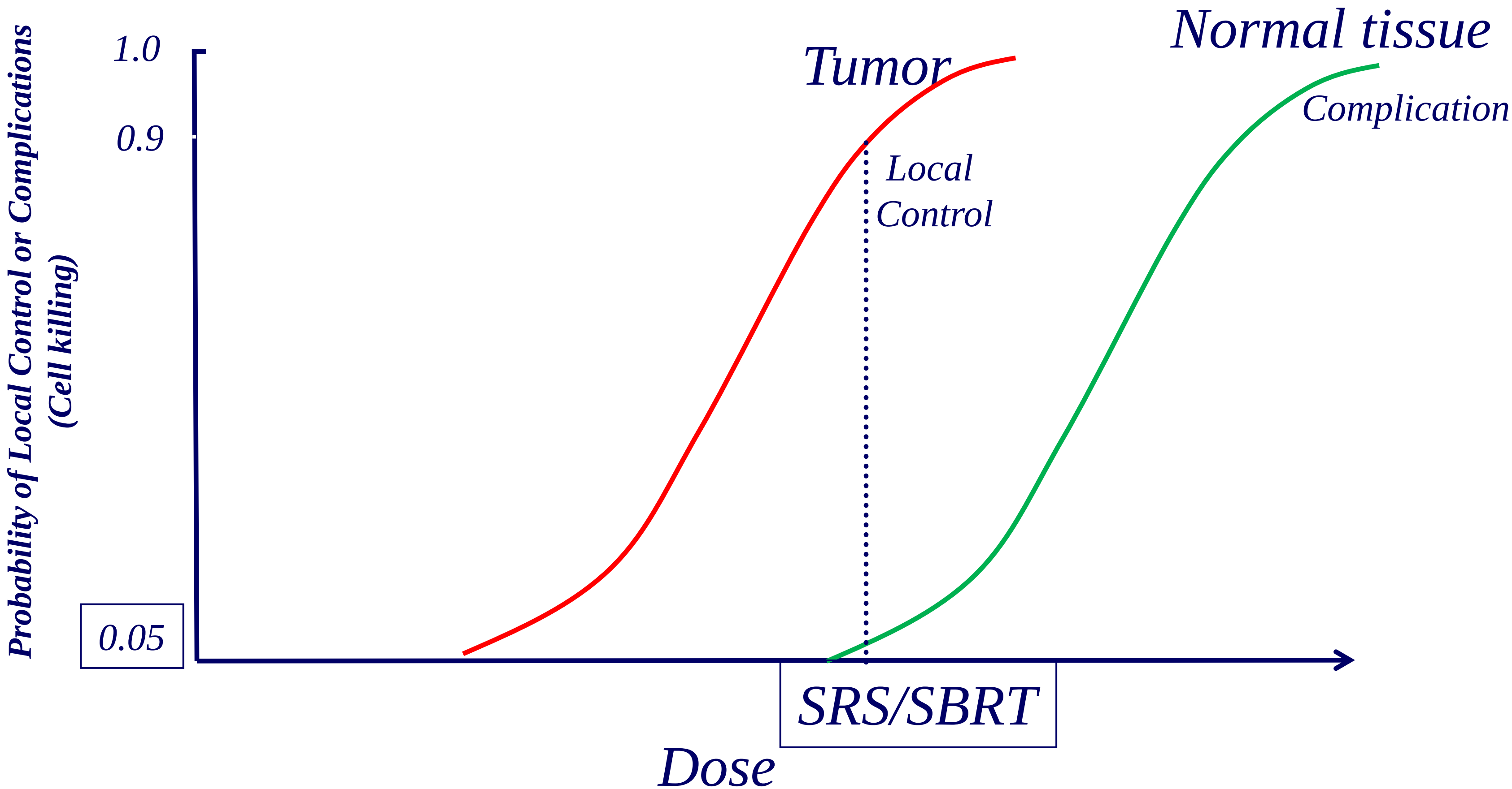
- Phillips Medical Systems
- Varian Associates

Employee of

- University of Texas M.D. Anderson Cancer Center

I will **NOT** include discussion of investigational or off-label use of a product in my presentation.

Therapeutic ratio revisited



In SBRT all cells in the target area are killed

We use geometry rather than radio-biology to spare normal tissues

This requires us to minimize margins

Stereotactic Radiosurgery (SRS)

a noninvasive technique that delivers a single high-dose fraction of radiation through multiple narrow radiation beams focused on an intracranial target localized stereotactically.

Stereotactic Radiation Therapy (SRT)

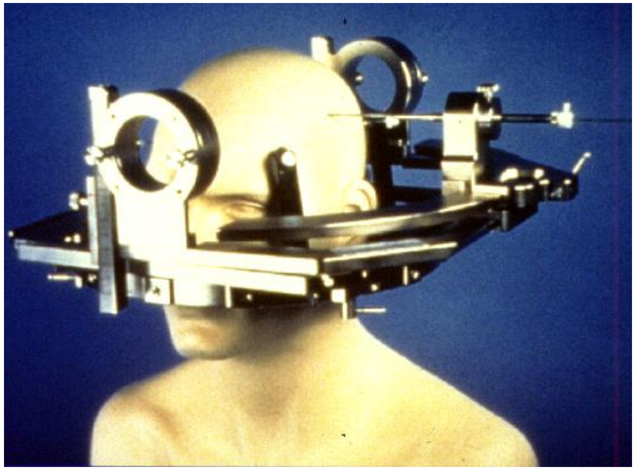
radiation similarly delivered but in multiple low-dose fractions.

Stereotactic Body Radiation Therapy (SBRT)

radiation similarly delivered but in multiple low-dose fractions in the body (non rigidly attached frame).

What is Stereotaxis?

A Method for locating points within the brain using an external, three-dimensional frame of reference, usually based on the Cartesian coordinate system



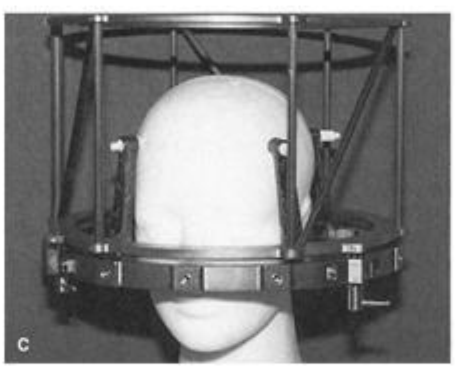
What is Stereotactic Radiosurgery (SRS)?

A minimum-invasive technique to deliver a single high dose of radiation to limited, well-defined target volumes, while avoiding nearby normal tissue and critical structures.

Head frames

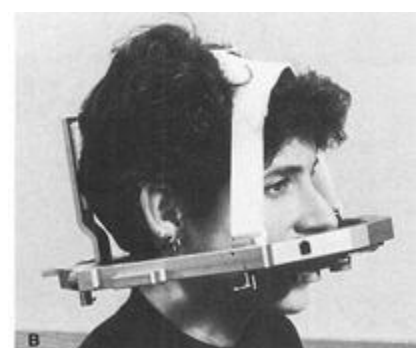
Fixed

- Attached to the skull by 4 screws
- Very stable (sub mm)
- Inasive
- Must stay on from imaging trough treatment
- Has localization add ons for MRI, CT, and Angio

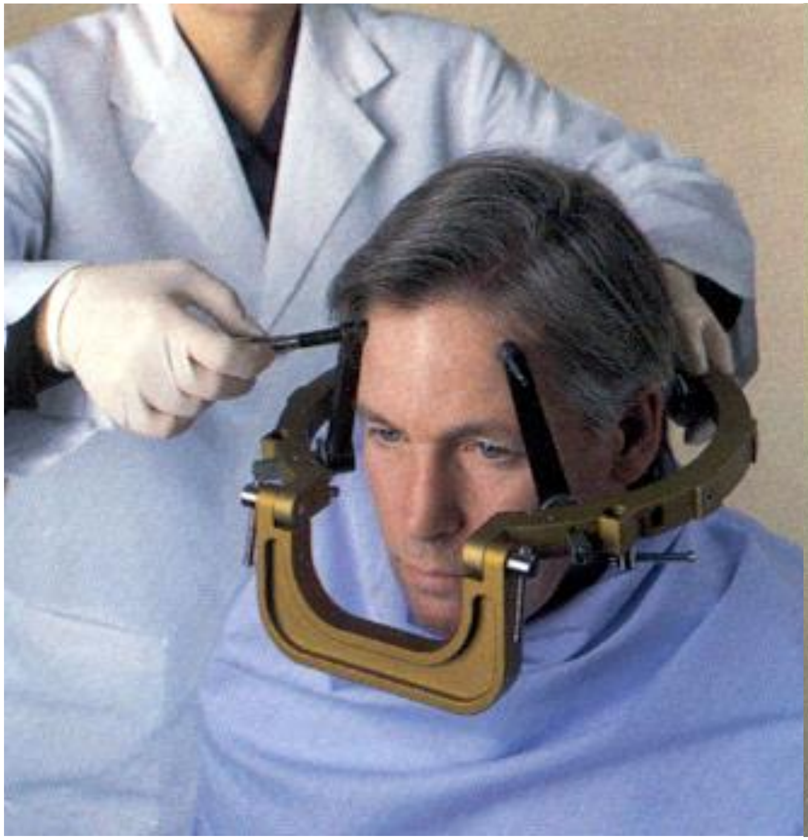


Relocateable

- Attached by a combination of vacloc, theroplastic and/or bite clocks
- Non-invasive
- Designed to be placed for a number of fractions
- Has localization add ons for MRI, CT, and Angio
- Does not allow the sub mm precision of the invasive frame

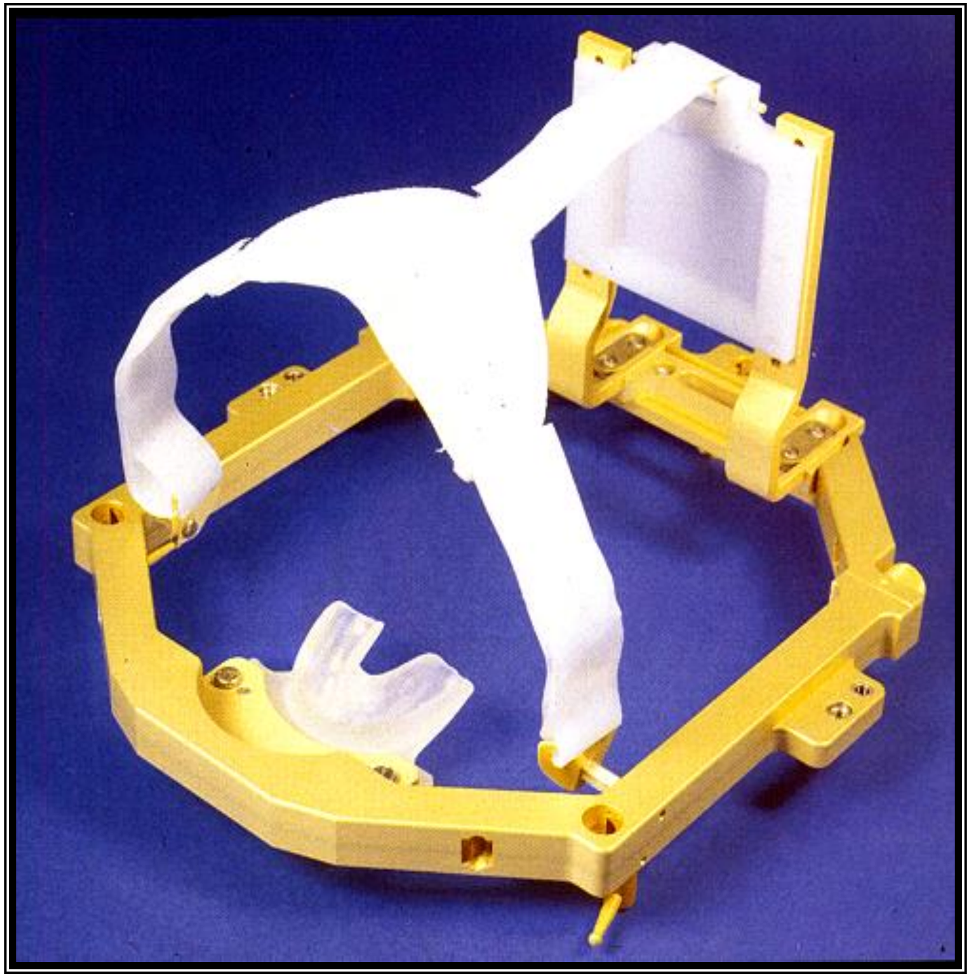


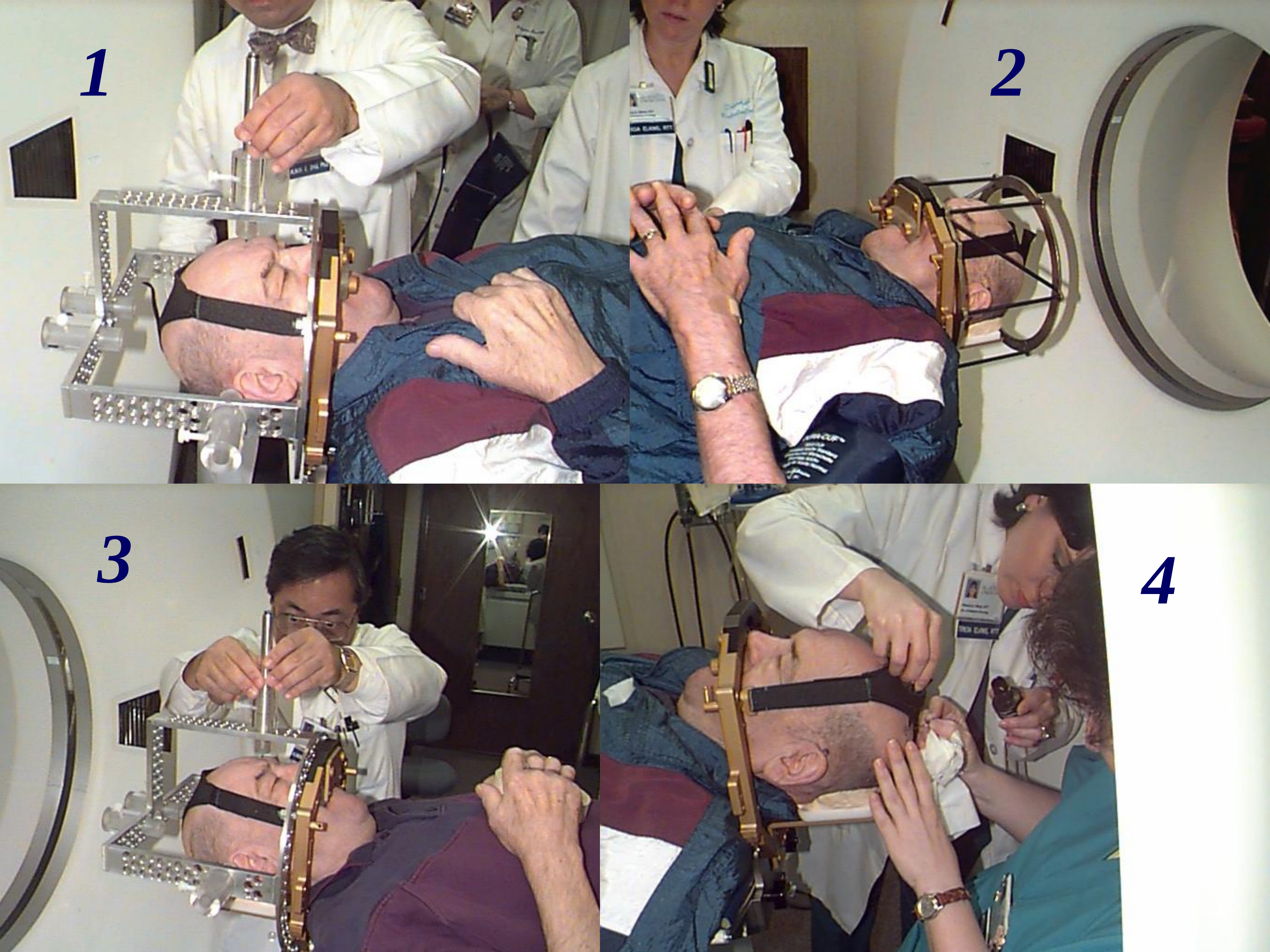
SRS Procedure
Frame Fixation




SRT (fractionated)

- Utilizes a relocatable frame known as the GTC frame(Giu-Thomas-Cosman)
- MMLC

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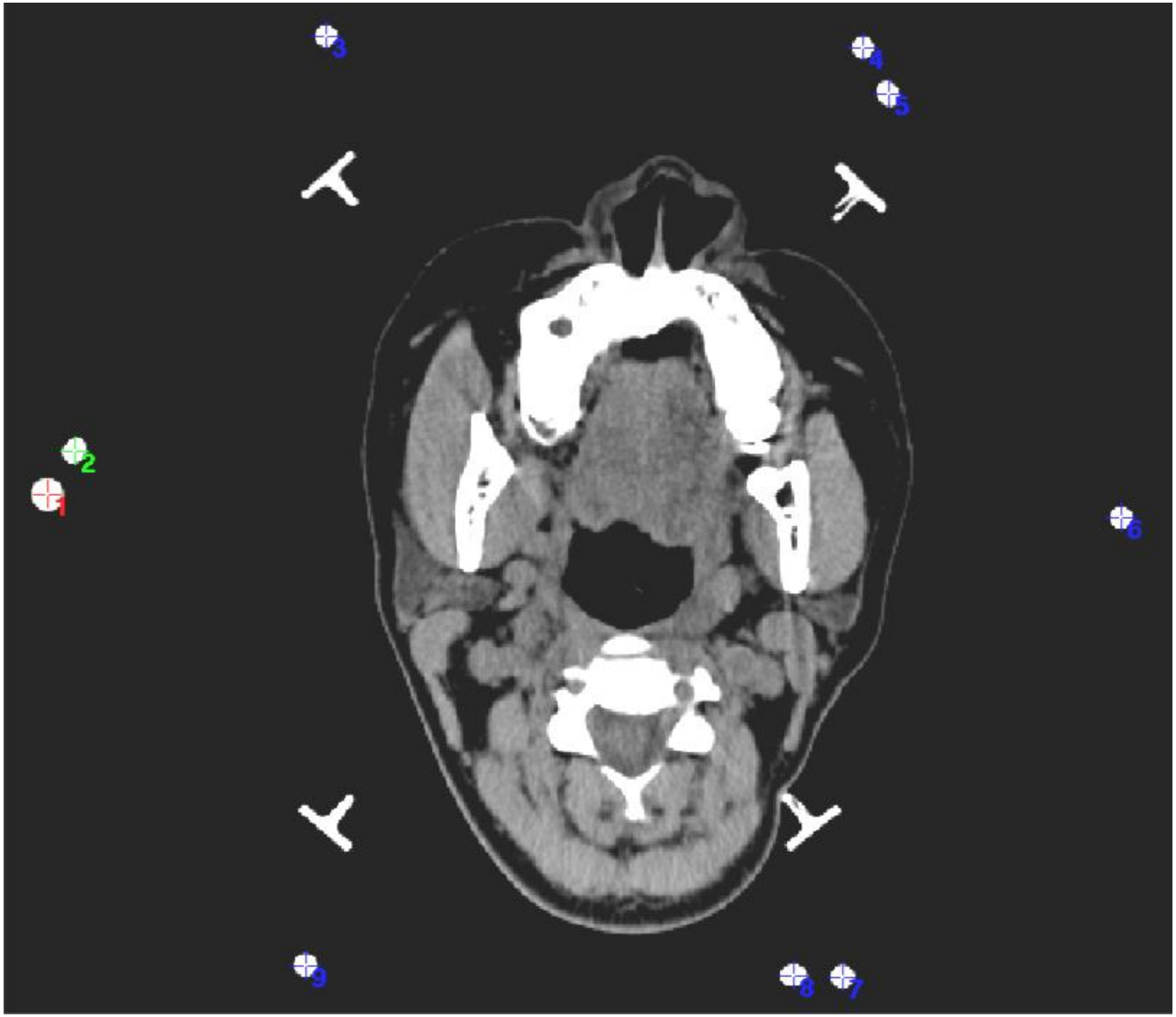
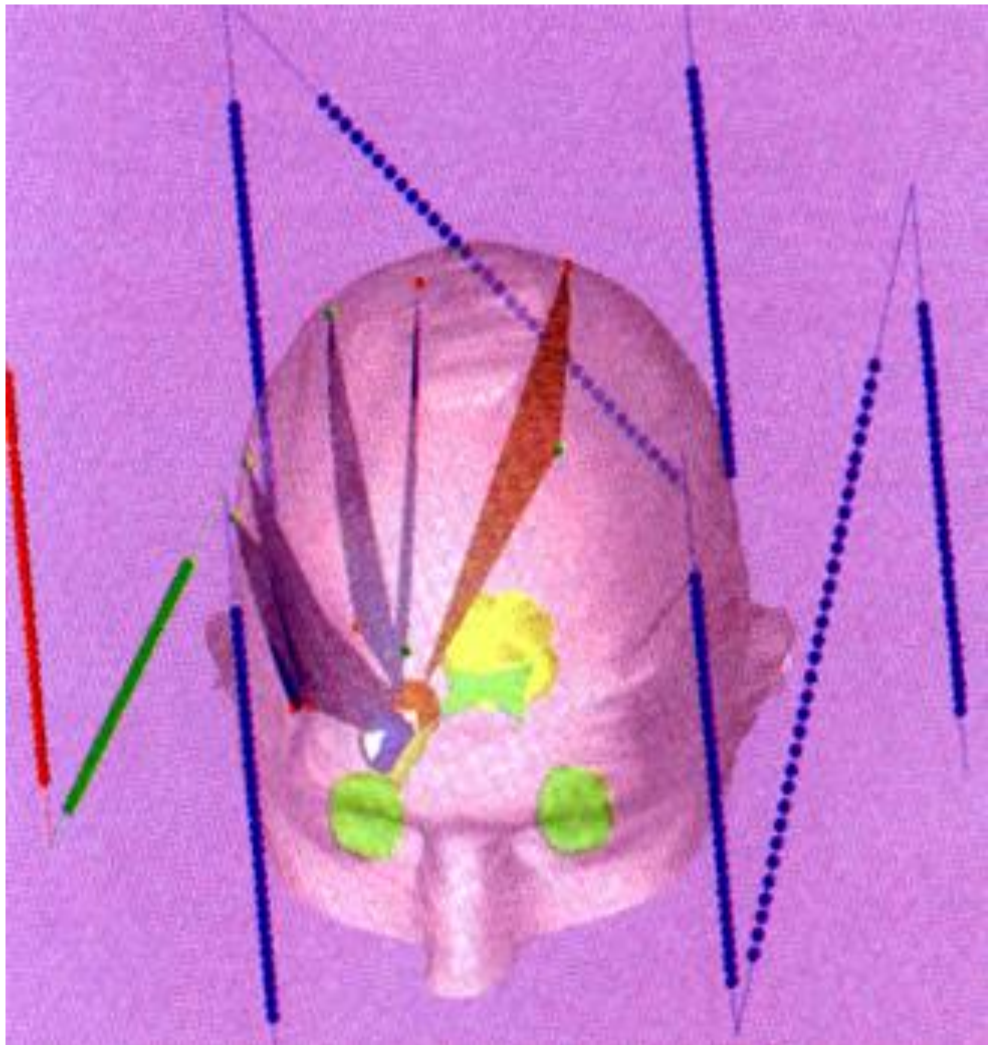
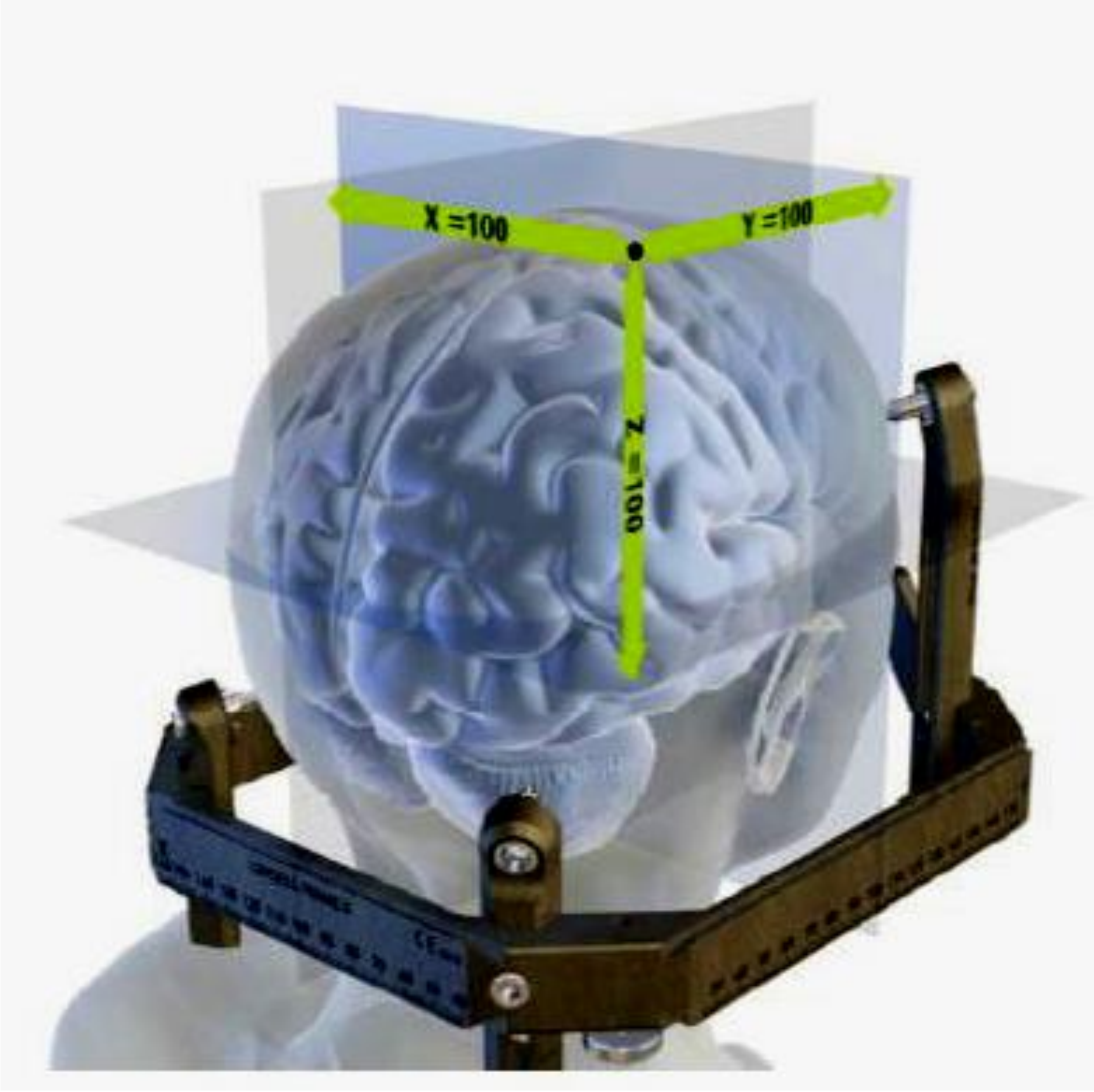
Imaging Scanning

Auto Detecting Rods





Cartesian Coordinate System



Tools for delivering SRS

Gamma Knife

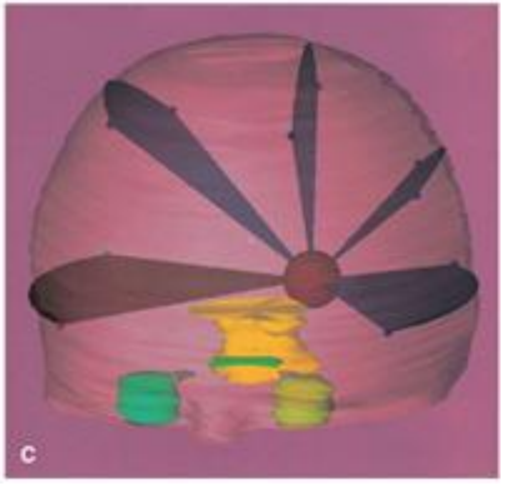
- Dedicated machine
- Around 200 ^{60}Co sources
- Very high precision ±0.3 mm
- Daily QA minimal (design of machine ensures precision)

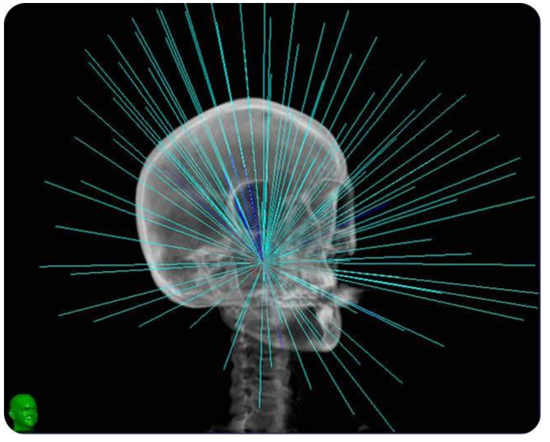
Linac

- General purpose machine
- Tertiary cones or mMLC can be used to obtain very small, high precision field sizes
- MLC allows the efficient treatment of complex shapes
- ± 1 mm precision
- Requires extensive QA each treatment day

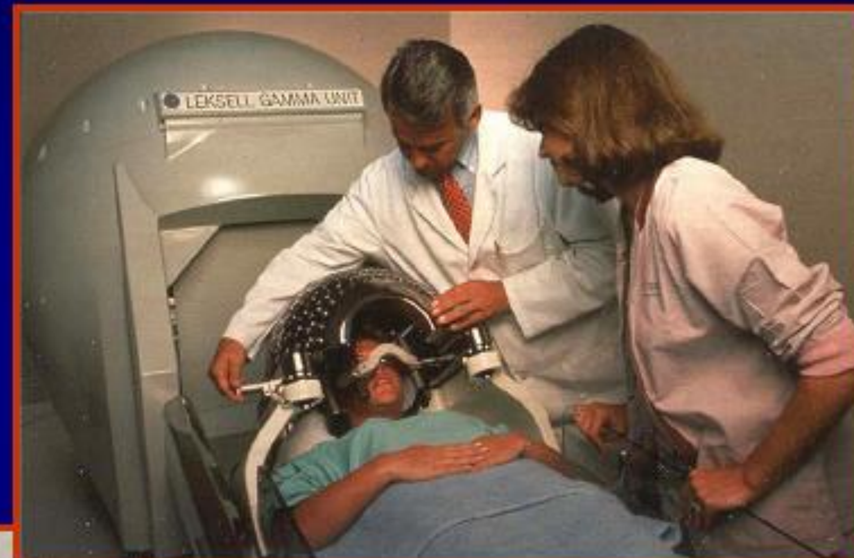
SRS planning

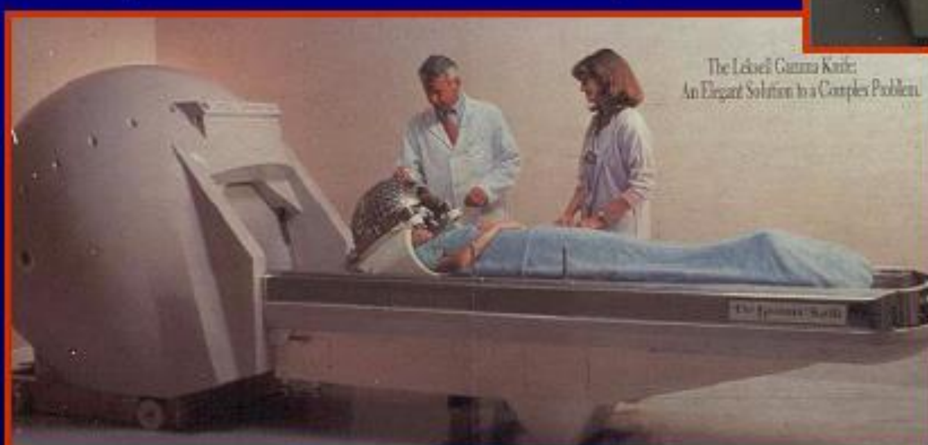
- Large number of beams are used
  - Gamma Knife
  - Cyber Knife
- Arcs are used
  - Linac based systems
- The greater the number of angles for delivery the sharper the fall off
  - Idea falloff (1/radius) of the lesions
    - Limits the size of lesions
  - Less beams the worse the fall of in the beam directions

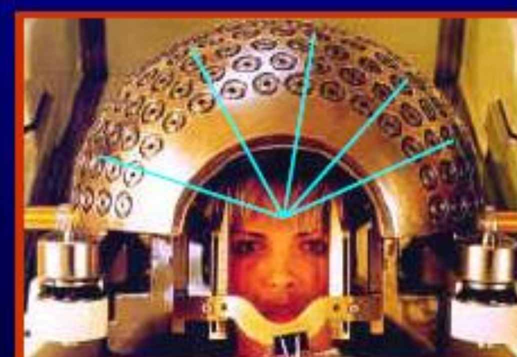




Gamma Stereotactic Radiosurgery (Gamma Knife)





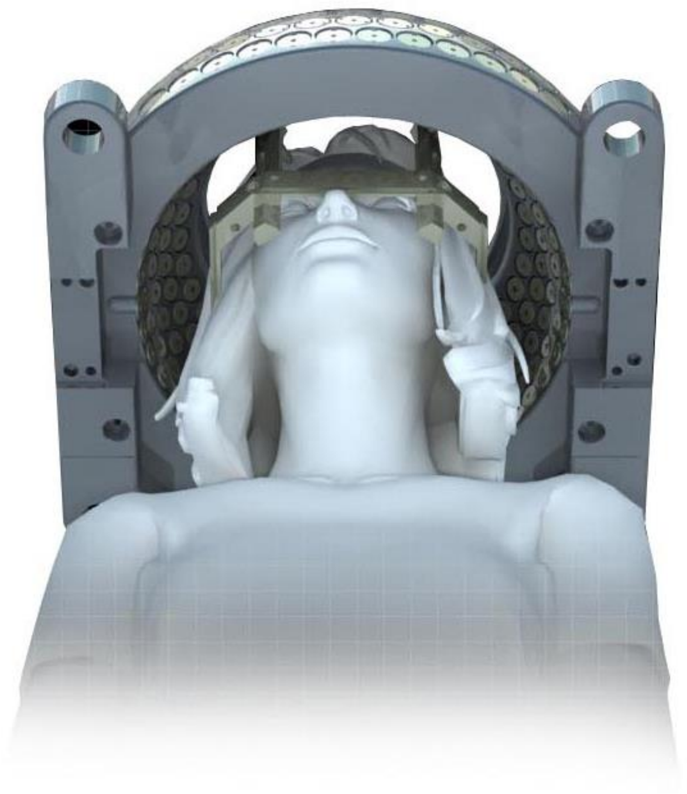


All Gamma knifes are not equal

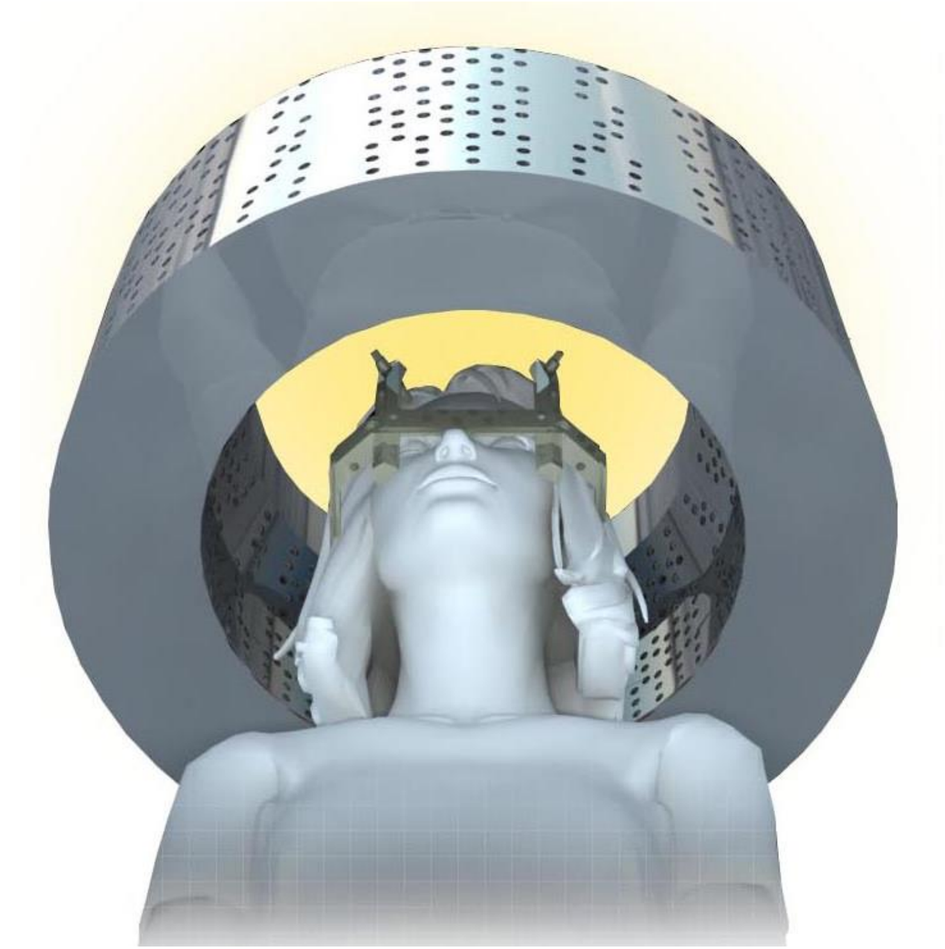
- Model U (A): Original
  - 201 Sources
  - Fixed sources and primary collimators
  - Patient is attached to a collimator helmet (4, 8, 14, and 18 mm collimator sizes)
  - Manual position of patient inside helmet to set isocenter location
  - Patient/collimator system slides into the machine and mates with primary collimator/source assembly
- Model B, C
  - Redesigned to facilitate source loading
  - C model introduced robotic positioning (still patient position within helmet)
- Perfexion
  - Major redesign (down to 192 sources)
  - Collimator helmets are gone 4, 8 and 16 mm collimators are integrated into the machine in a collection of sectors
  - Collimators are fixes, sources move.
  - Entire patient is moved using robotic couch to set isocenter locations

Leksell Gamma Knife®

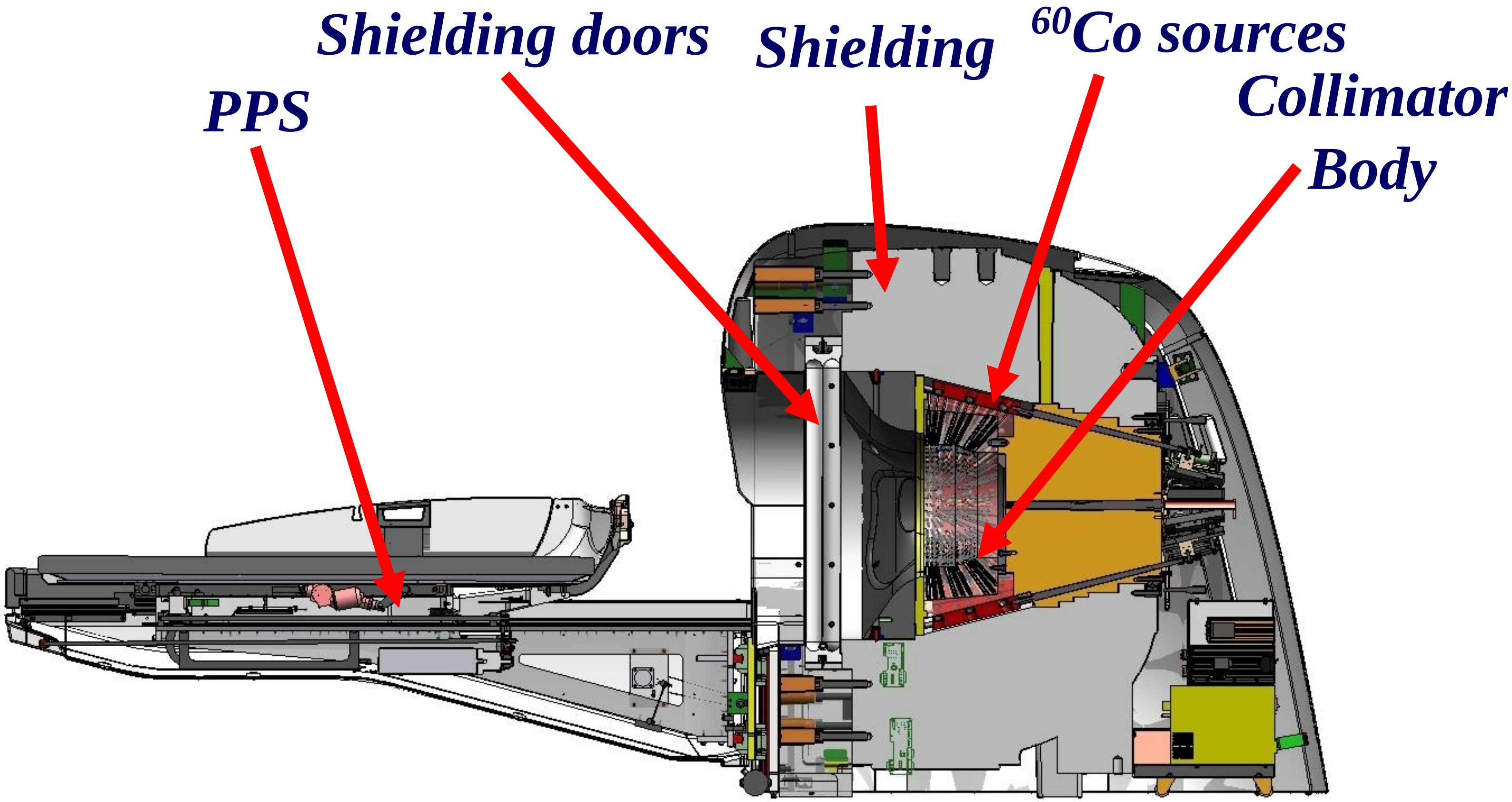
Leksell Gamma Knife C



Leksell Gamma Knife PERFEXION



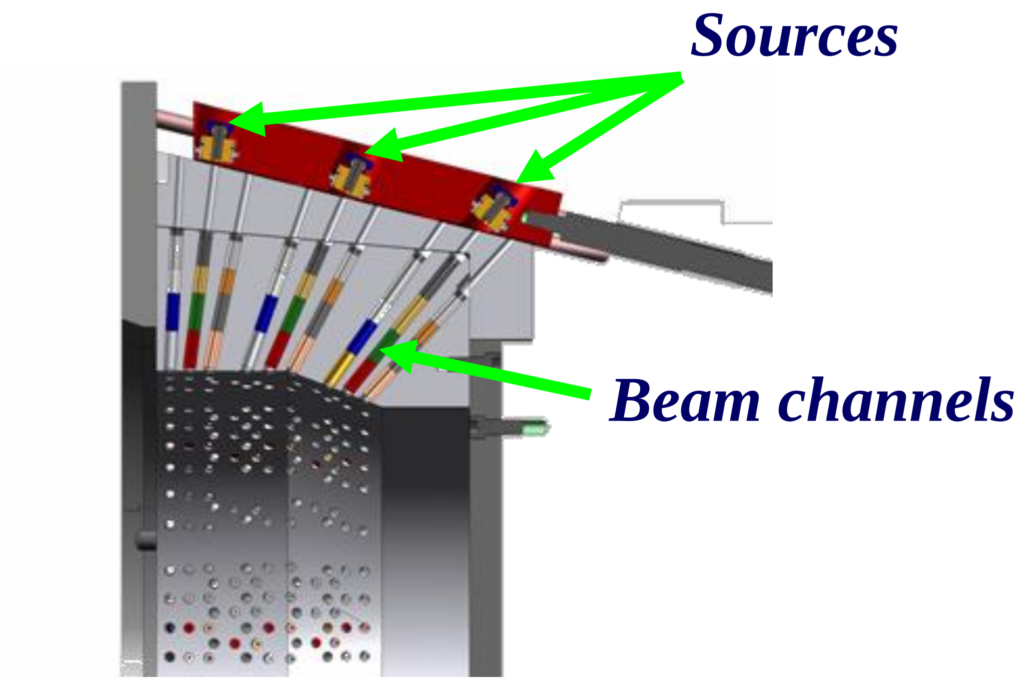
Radiation Unit PERFEXION™

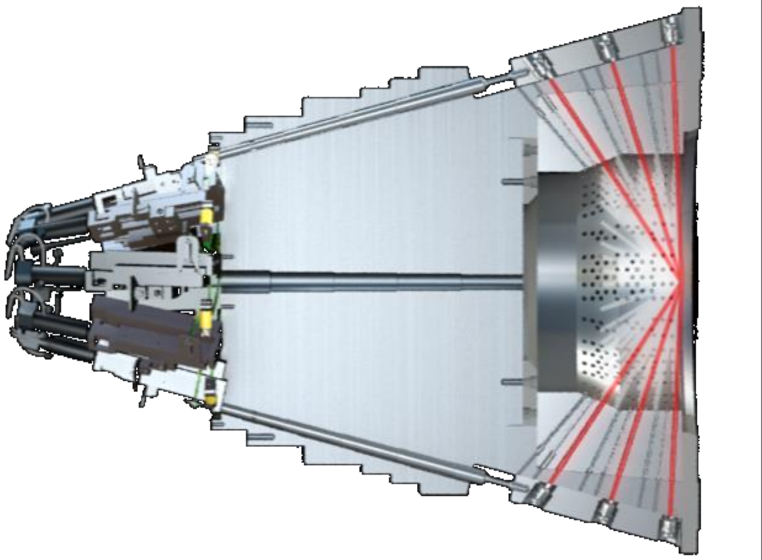


Collimator System (Beam Shaping)

5 different sector position

- ***Home (back most)***
- ***8 mm***
- ***Sector Off***
- ***4 mm***
- ***16 mm (front most)***





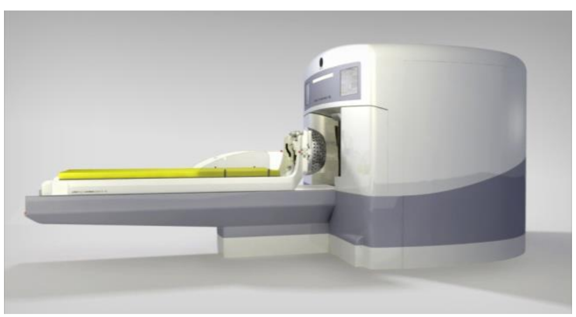
Collimator System -Comparison

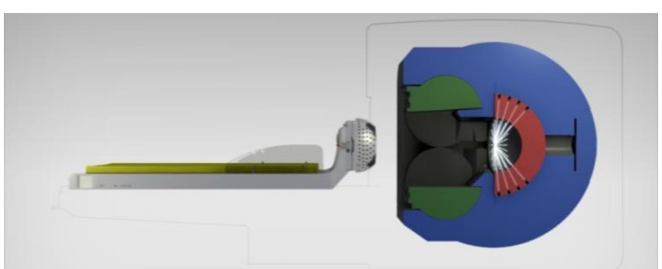
Leksell Gamma Knife® 4C

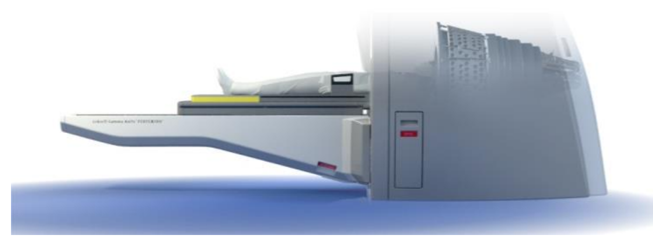
- Collimator system with four collimator helmets
- Manual change of collimator size.
- Manual plugging

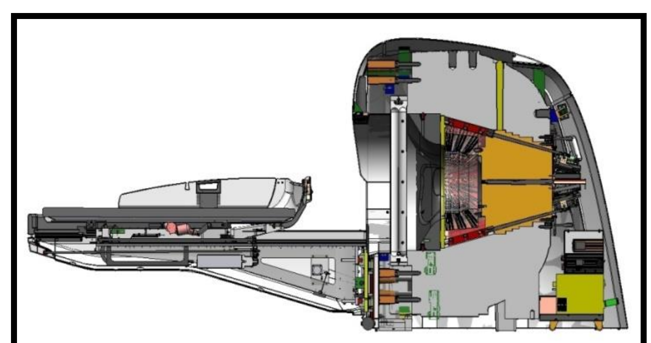
Leksell Gamma Knife® Perfexion™

- Collimator system built in.
- Automatic change of collimator size
- Automatic plugging by sectors
- Sector off during patient positioning
- Sector home during system idle



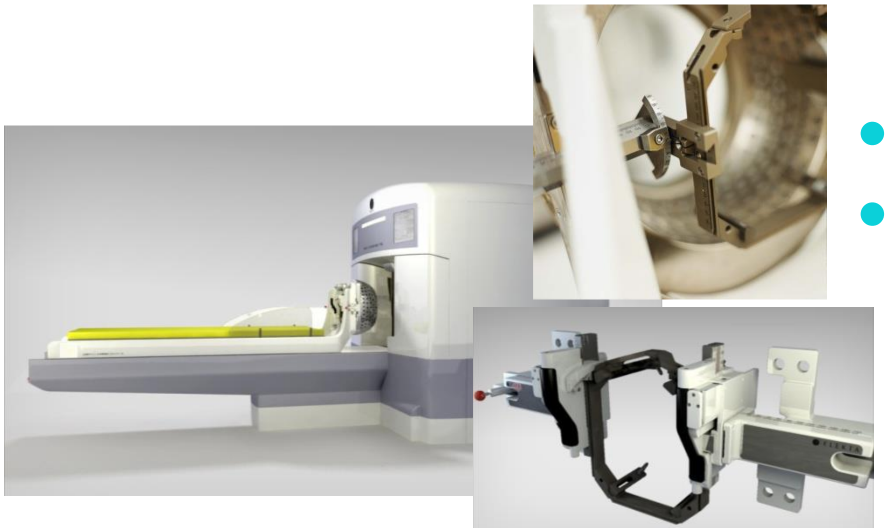






Patient Positioning System - Comparison

Leksell Gamma Knife® 4C



- Couch moving patient into cavity
- Automatic Positioning System or manual trunnion setting positions patient's head.

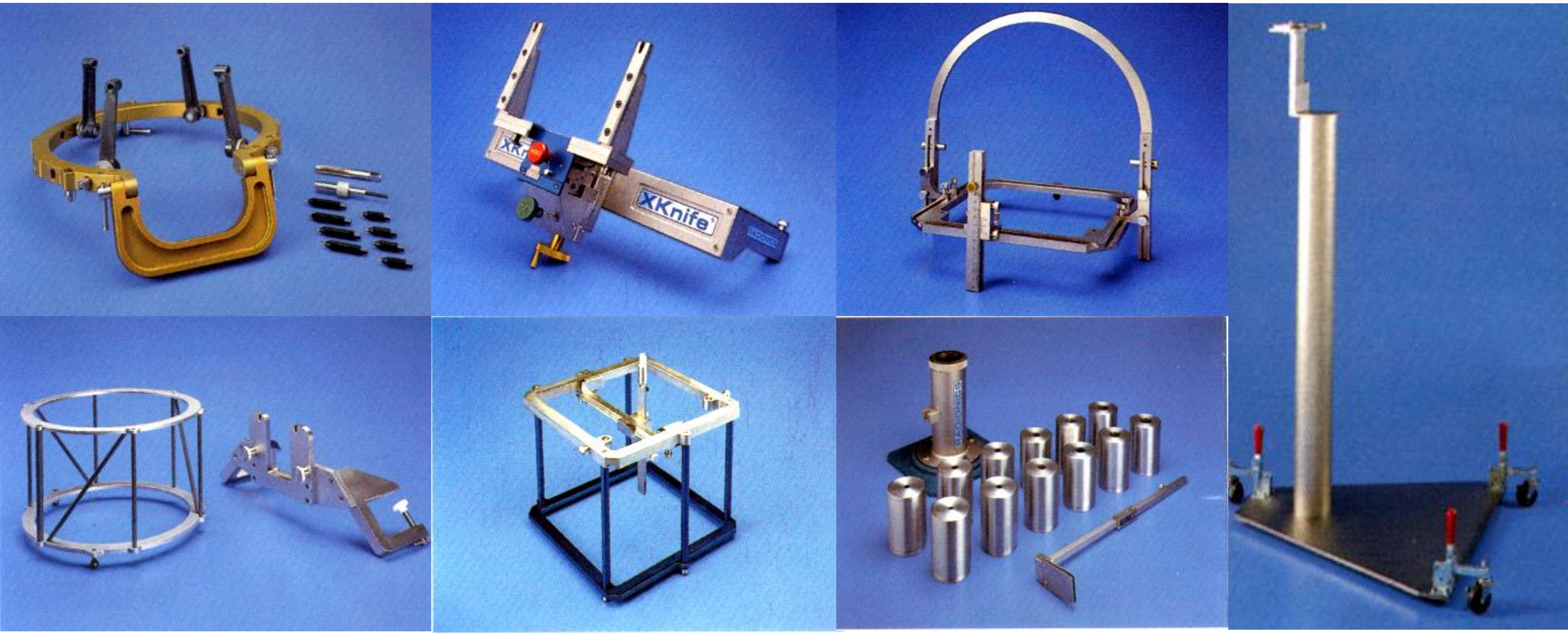
Leksell Gamma Knife® Perfexion™

- Whole body movement.
- The couch is a Positioning System.

Linac based systems

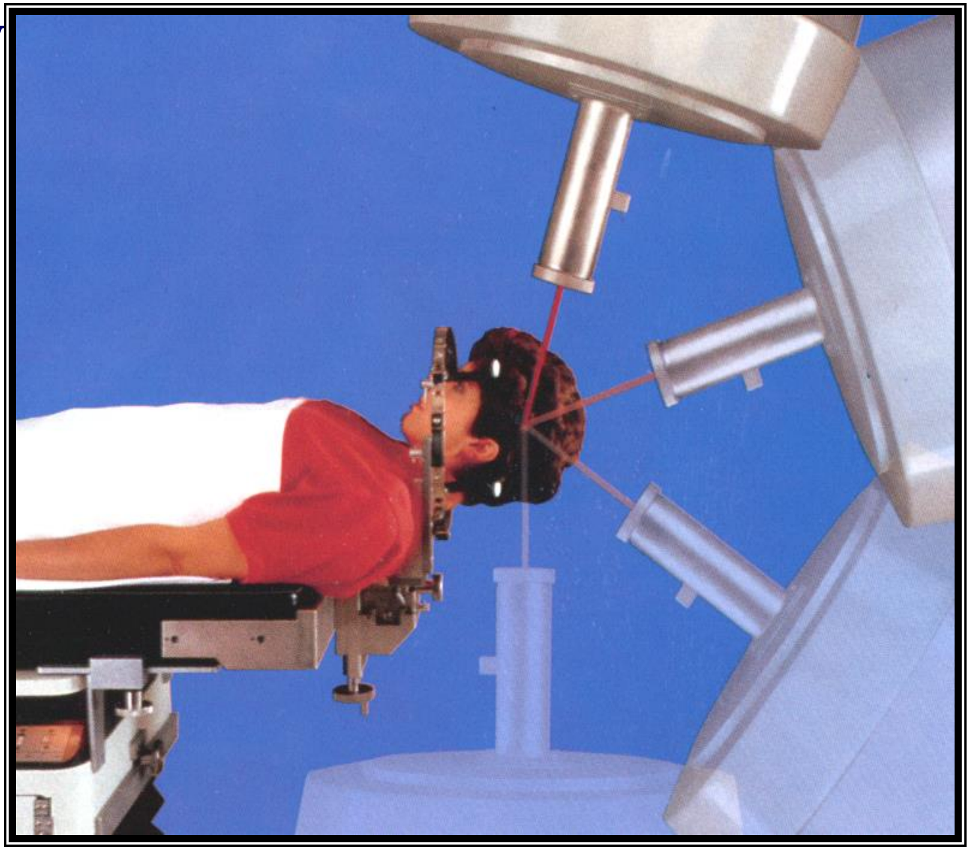
- Collimation system added to linac
  - Usually a cone holder and a collection of fixed cones (8 mm – 40 mm)
  - Minimultileaf is also available
  - Collimation closer to the patient reduces the geometric penumbra
- Head frame may be attached to the couch or to a floor stand
- Require QA on each day of use to ensure radiation isocenter and tumor can be aligned
  - Generally use the lasers as a transfer standard
- Not all linacs have the mechanical accuracy required for SRS (but many do)

Stereotactic Instrumentation
(Integra/Radionics)



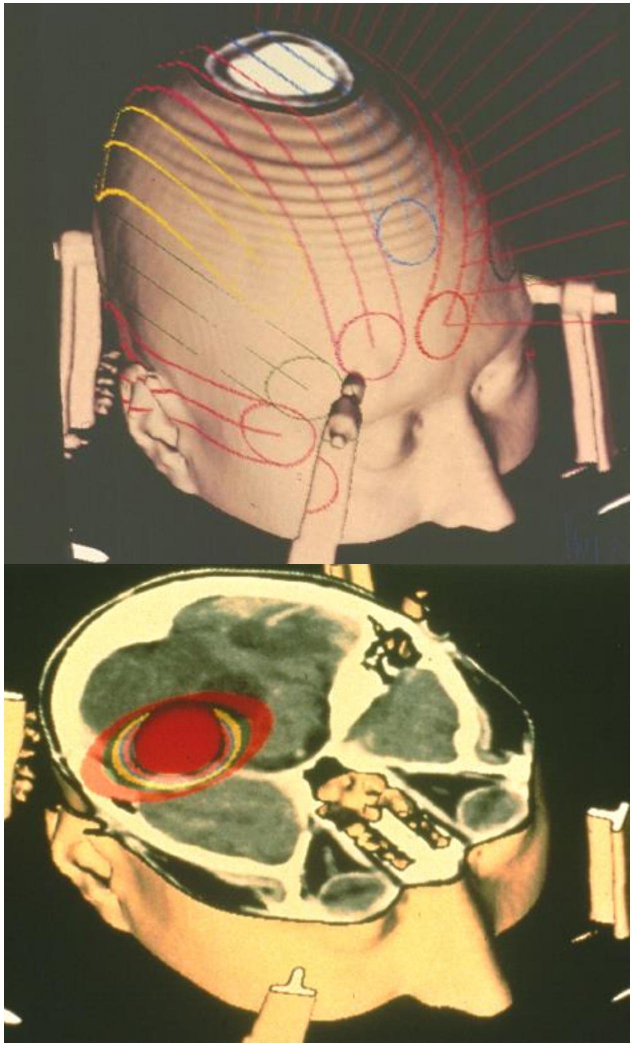
What is Linac-Based SRS?

- Delivers a narrowly collimated x-ray beam, while the gantry rotates around the target.
- The target is positioned at the center of the gantry rotation



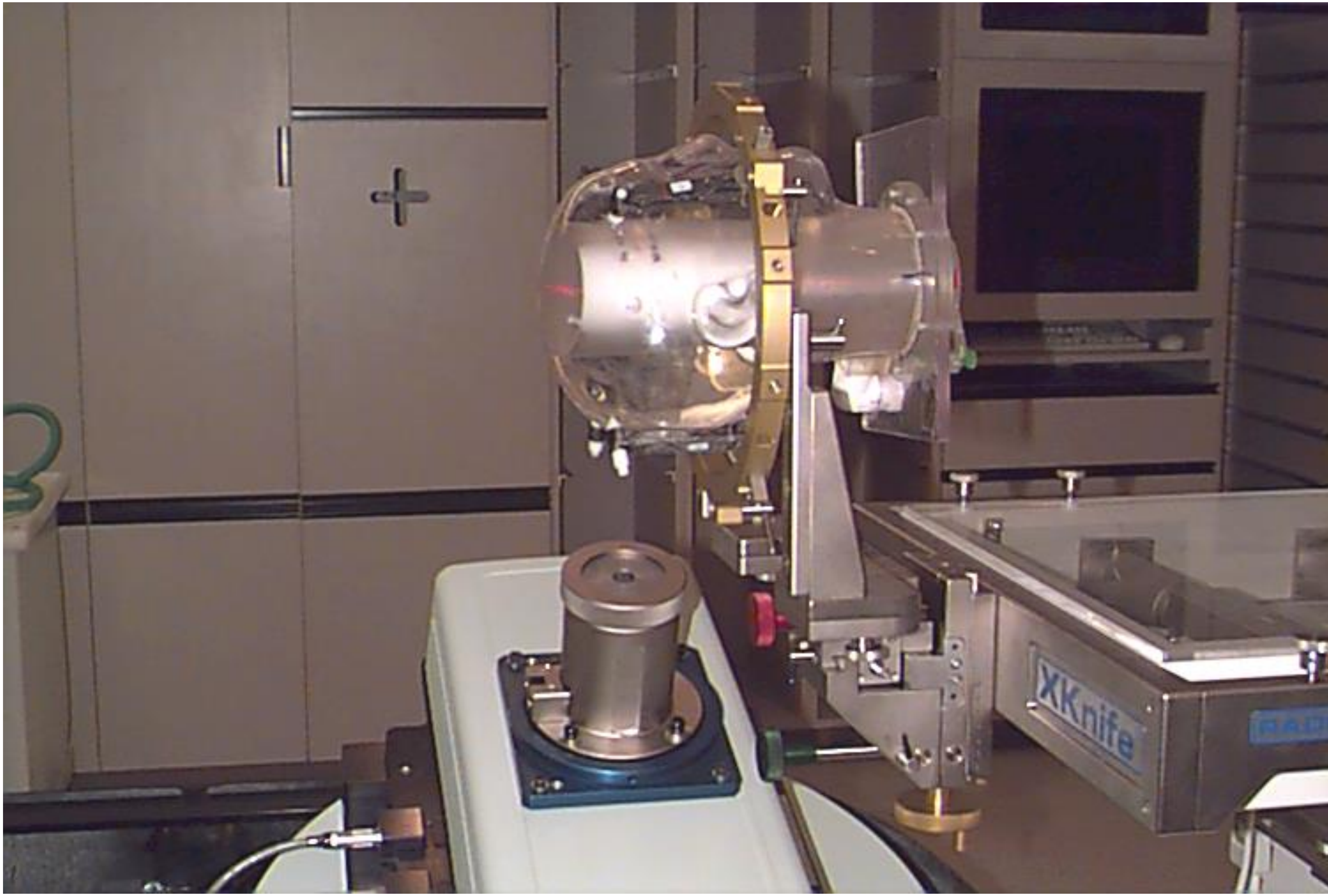
Linac-Based SRS

- Process is repeated for a number of different couch angles
- This enables the target to be caught in a crossfire of x-ray beams which delivers a lethal dose to the target while sparing surrounding tissue

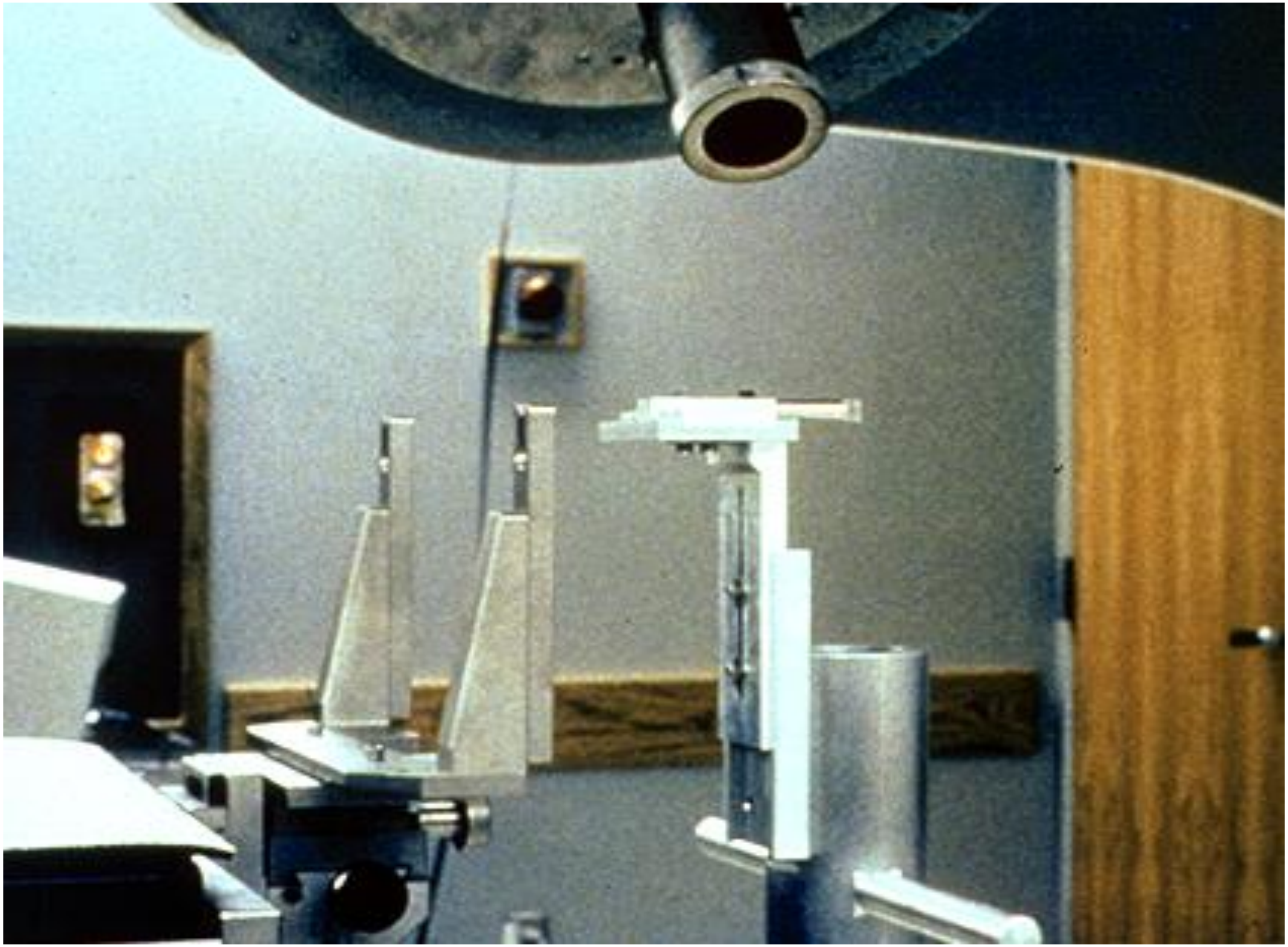


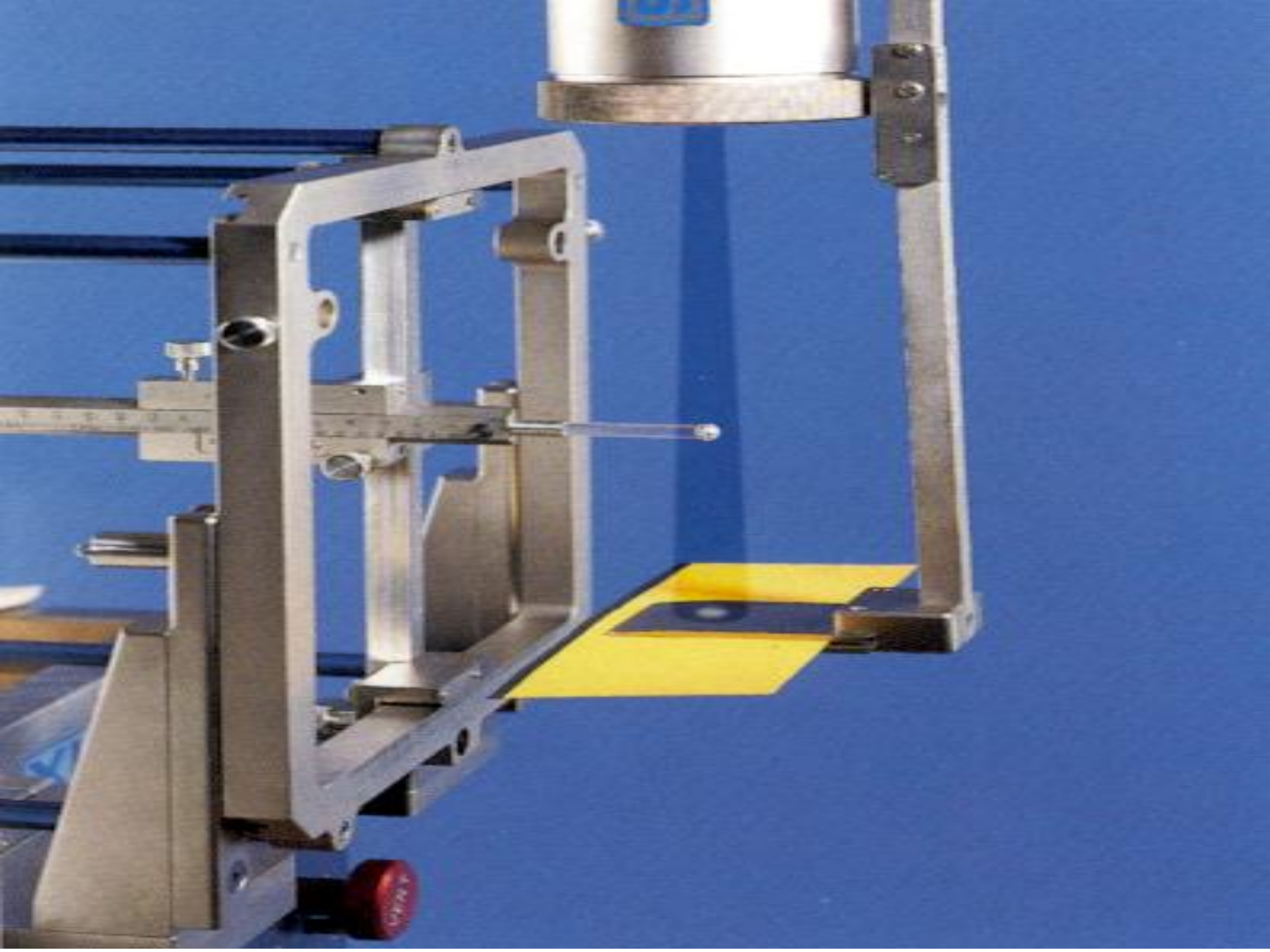
Treatment

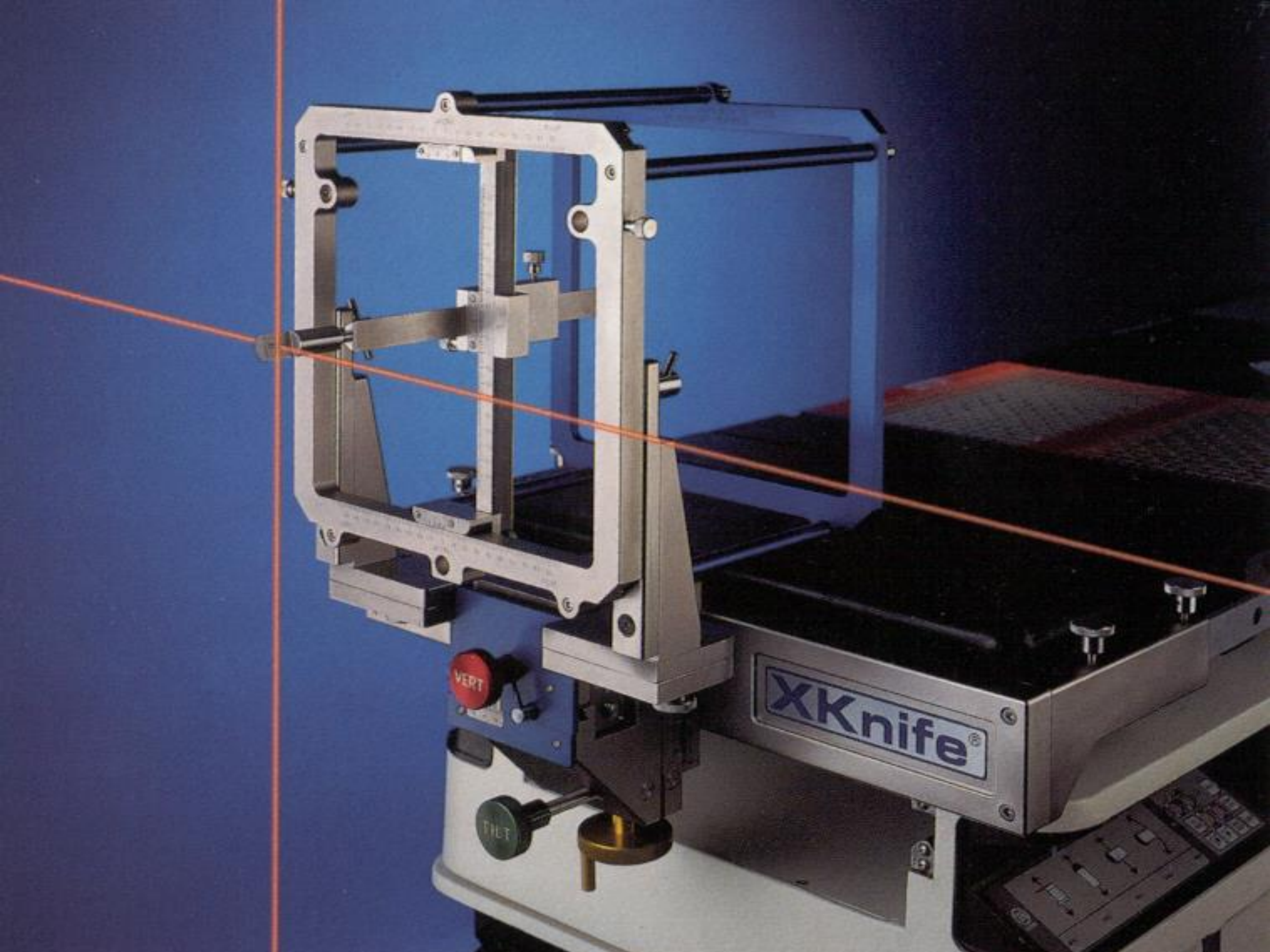
- Typically 5-7 arcs, about 60 degrees each
- 5-10 MU/degree with approx 300-600mu/arc
- 300MU/min equates to 1-2mins per arc
- Total treatment is 5-10 min beam on time
- Room entries between arcs to move couch and re-check alignment

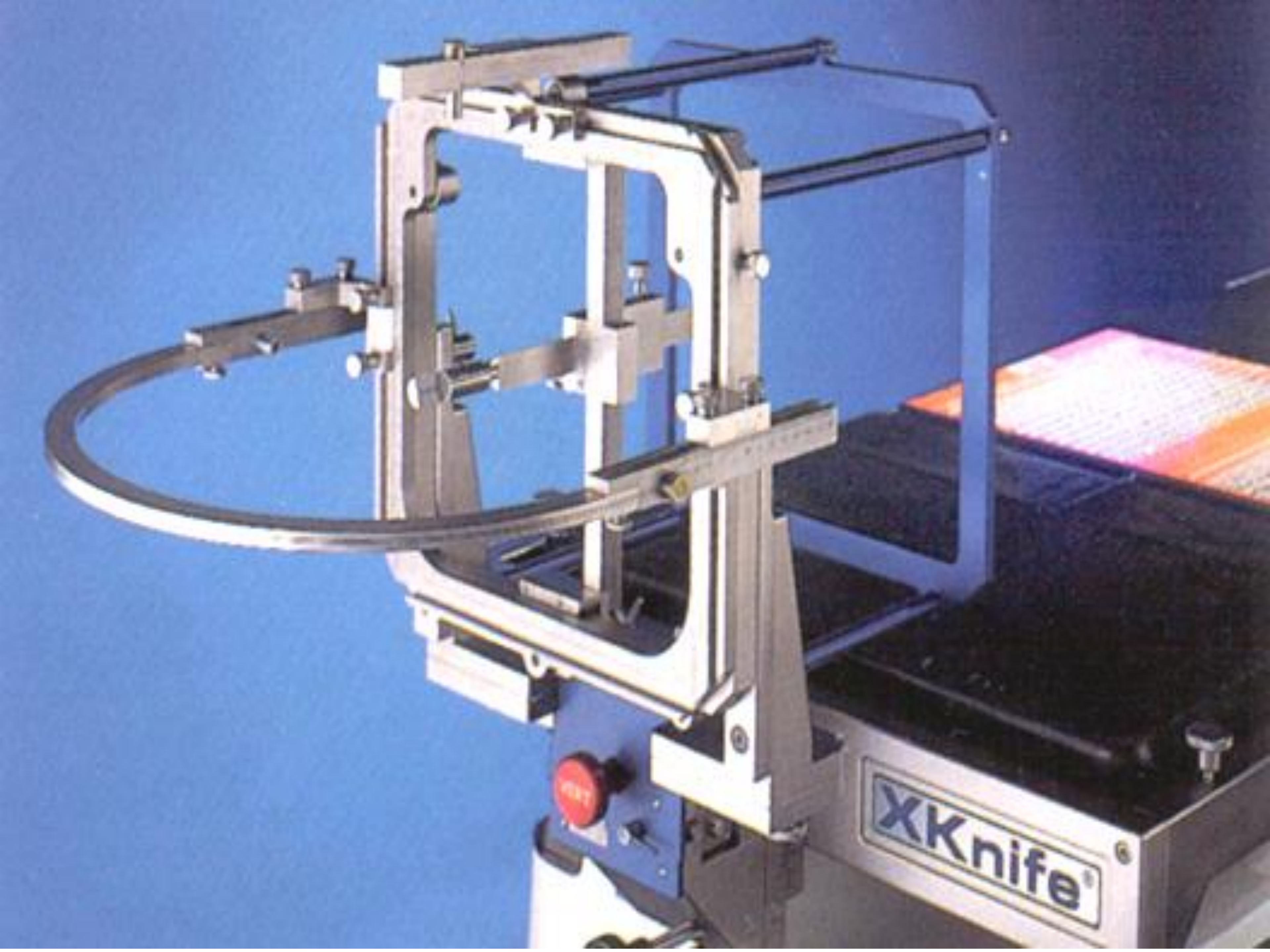

XKnife

Pre-treatment QA

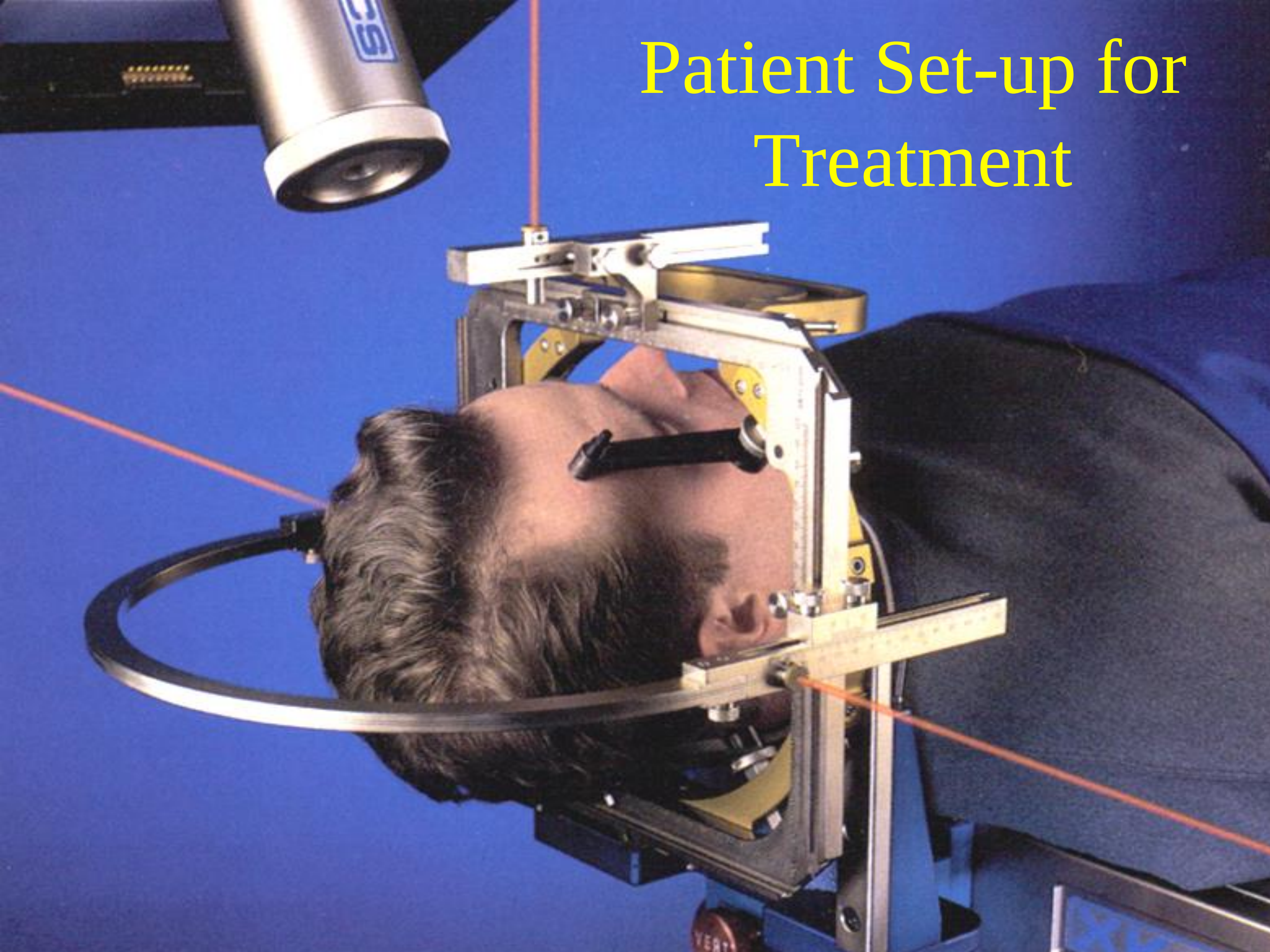





VERT
TILT
XKnife®


XKnife

Patient Set-up for Treatment



Treatment Delivery

Specialty linac systems Integrated Imaging for positioning

- Novalis (Novalis TX)
  - Varian Trilogy
    - mMLC (HD120)
    - 6 DOF couch
  - Orthogonal oblique imaging (during treatment)
- Cyberkinfe
  - Compact 6 MV linac
  - Either fixed cones or variable circular collimator (IRIS)
  - Orthogonal oblique imaging (during treatment)

Novalis® Hardware Components

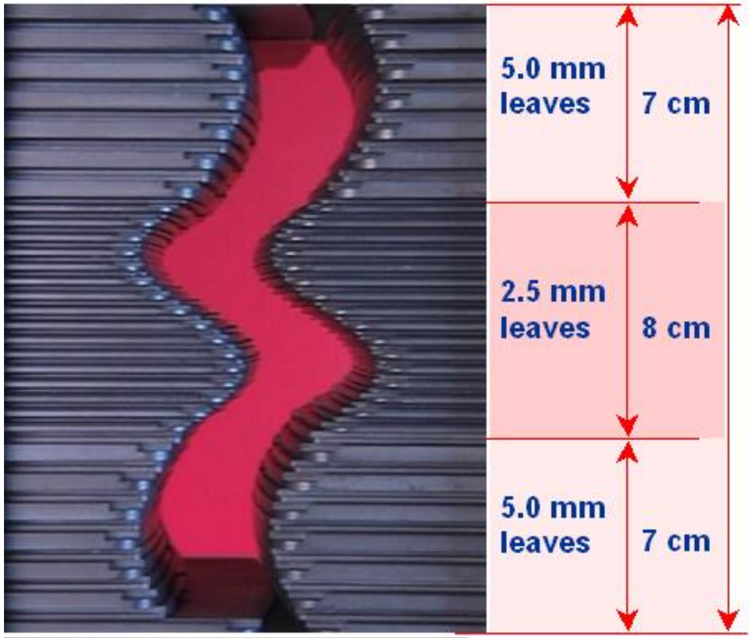
a-Si Flatpanel

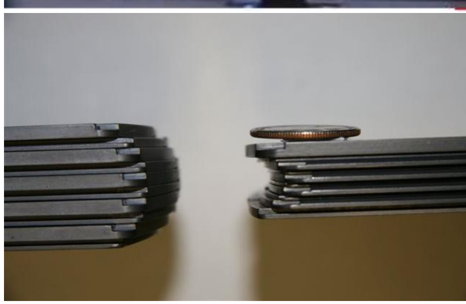
a-Si Flatpanel

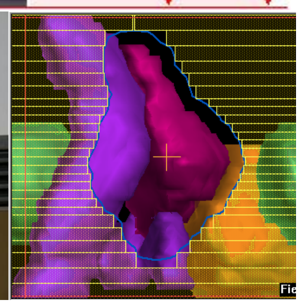
X-ray source

X-ray source

HD120 Beam Shaper.







- 32 central pairs 2.5 mm leaves
- Large 22 X 40 cm^2 fixed field size
- Maximum leaf speed 2.5 cm/sec
- Sharp penumbra <3 mm for SRS
- Dynamic Treatment Capabilities
- Overall clinical precision guaranteed 0.5mm radius, recent installations <0.3mm

CyberKnife G4

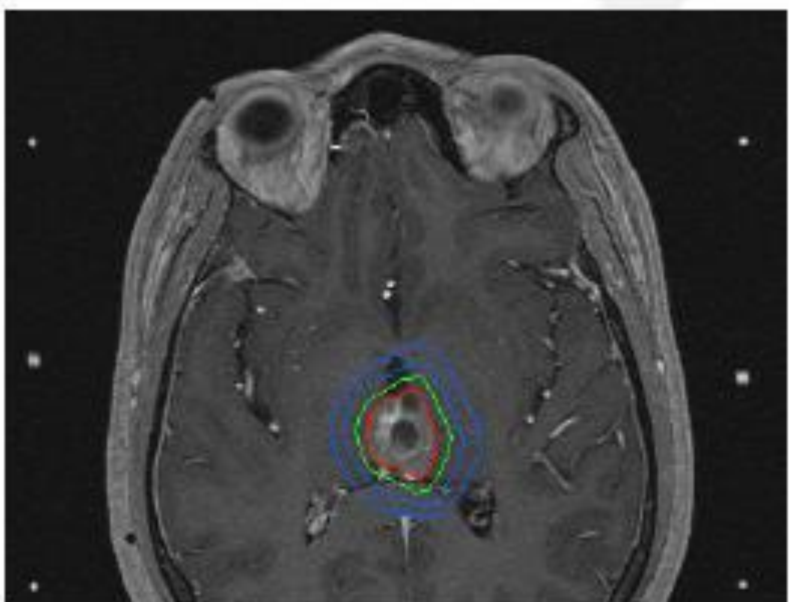
Prescription for SRS

- RTOG recommendations:
  - 24Gy for 1cm - 2cm cones
  - 18Gy for 2.25-3cm cones
  - 15Gy for 3.25-4cm cones
- Modifications may be made depending on disease radiosensitivity, prognosis and other factors

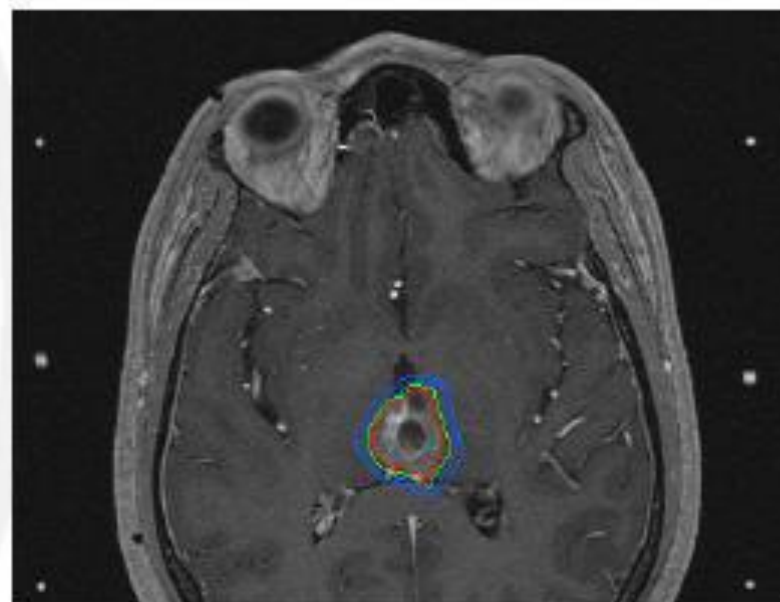
"Quality" of a plan

Conformity describes only how well the prescription dose is fitted to the target volume, whereas selectivity also takes irradiation to normal tissue into account.

Conformal



Conformal and selective



SRS Quality Metrics

Derived Metrics for SRS quality analysis

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● *Special Feature*

RADIATION THERAPY ONCOLOGY GROUP: RADIOSURGERY QUALITY ASSURANCE GUIDELINES

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LUIS SOUHAMI, M.D.,[3] ALAN HIRSCHFELD, M.D.,[4]
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A multidisciplinery Radiation Therapy Oncology Group (RTOG) task force has developed quality assurance guidelines for radiosurgery. The purpose of the guidelines are fourfold: (1) To ensure that participating institutions have the proper equipment and appropriate technique(s) to administer radiosurgery; (2) to outline a standard data set for each treated patient to assess protocol compliance; (3) to define minor and major deviations in protocol treatment; and (4) to set forth clinical data necessary to determine treatment efficacy, including failure patterns, and treatment toxicity. These guidelines are being implemented into active and developing radiosurgery protocols.

Quality assurance, Radiosurgery, Gamma knife, Linear accelerator, Stereotactic.

Coverage: If the 90% of prescription isodose line completely encompasses the target, the case is considered per protocol. If the 90% of prescription isodose line does not completely cover the target, but the 80% of prescription dose isodose line does completely cover the target, this shall be classified as a minor deviation. If the 80% of prescription dose isodose line does not completely cover the target this shall be classified as a major acceptable deviation.

$$Q(quaility\ of\ coverage) = \frac{I_{min}(minimum\ dose\ to\ the\ target)}{RI(prescription\ Isodose)}$$

Homogeneity index: A figure of merit for dose homogeneity within the target volume shall be determined as the maximum dose in the treatment volume divided by the prescription dose (ratio MDPD). This ratio shall be less than or equal to 2.0, and if achieved, the case will be per protocol. MDPD ratio greater than 2 but less then 2.5 shall be classified as minor deviation. MDPD ratio greater than 2.5 shall be classified as a major acceptable deviation.

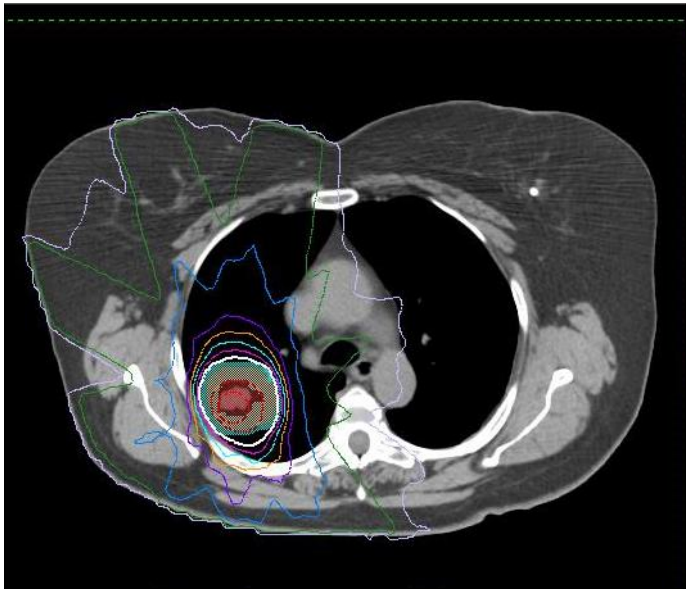
$$HI\ (homogeneeity\ Index) = \frac{I_{max}(maximum\ dose\ to\ target)}{RI(Prescription\ isodose)}$$

Conformity index: The volume of the prescription isodose surface shall be determined (this may be obtained from the dose volume histogram, or by measuring the area of the prescription isodose on sequential levels). A figure of merit for conformation of the prescription dose to the target shall be determined as the volume of the prescription isodose surface divided by the target volume (ratio PITV). This ratio shall be between 1.0 and 2.0; and if achieved, there will be no deviation from protocol. PITV ratios less than 1 .O but greater than 0.9 shall be classified as minor deviations. PITV ratios less than 0.9 shall be classified as major deviations. PITV ratios between 2.0 and 2.5 shall be classified as minor deviations, while PITV ratios greater than 2.5 shall be classified as major acceptable deviations.

$$CI(conformity\ index) = \frac{V_{RI}(Volume\ encompassed\ by\ the\ prescription\ isodose\ line)}{TV(target\ volume)}$$

SBRT

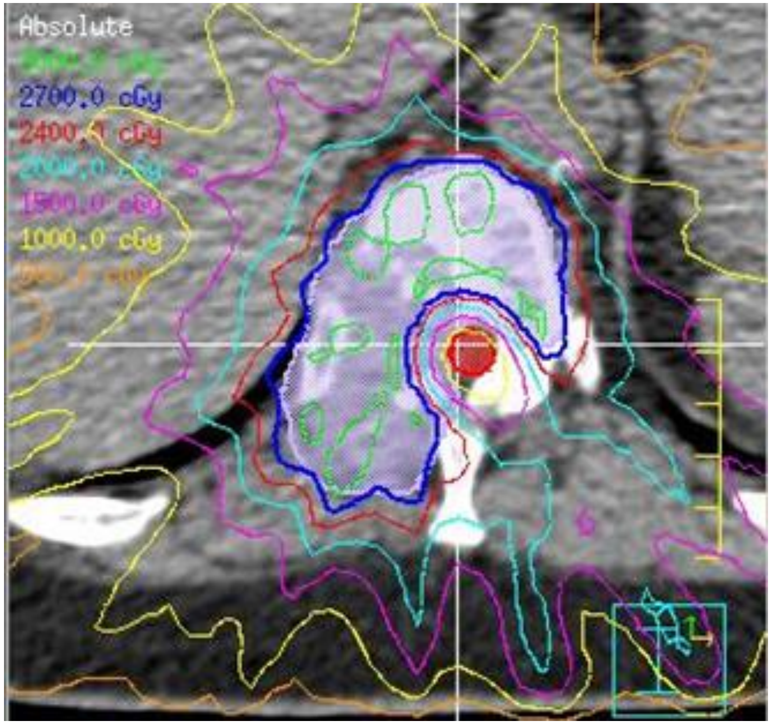
How is SBRT different from traditionally fractionated XRT



- Tighter margins
  - In-room imaging
  - Immobilization
  - Planning
- Higher dose/fractions
  - BED
- Lower number of fractions
  - Less opportunity to correct errors during treatment
  - Daily setup more critical

Tighter Margins

- Spine SBRT at MDACC
  - 0 mm PTV
    (physician determined CTV)
- Lung/Liver SBRT s
  - 5 mm PTV (no CTV)

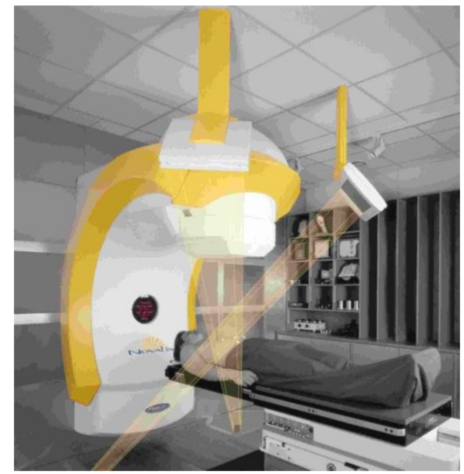


How are the tight margins achieved

- Treatment planning that prioritizes good falloff over dose homogeneity in the target
- Tight tolerances on the treatment machine
- Good patient immobilization
- Daily imaging of the tumor or a good surrogate
- 2^{nd}ary verification of setup
  - Independent imaging system
  - External frame (we won't talk about this)

Alignment accuracy for SBRT

- Alignment of Isocenter of setup modality vs treatment beams must be known
- Initial Verification
  - End to end test
- Monthly QA
  - Alignment check (winston-Lutz type test)
- Daily QA
  - Check for gross changes (2 mm level)



Biological Effective Dose (BED)

- **BED = nd [1+d/(α/β)]**
- **BED:**
  - **72 Gy: 60 Gy in 30 Fx (Conventional RT)**
  - **84 Gy: 70 Gy in 35 Fx**
  - **96 Gy: 60 Gy in 10 Fx**
  - **106 Gy: 48 Gy in 4 Fx (Japan Oncology Group. I/C)**
  - **112.5 Gy: 50 Gy in 4 Fx (MD Anderson, PTV)**
  - **119 Gy: 70 Gy in 10 Fx (MD Anderson/Beijing, GTV)**
  - **180 Gy: 60 Gy in 3 Fx (RTOG, 80% Isodose)**

Hypo-fractionated Radiation Therapy

Author	Year	PT #	Total Dose	# of Fractions	BED (α/ß = 10)	**OS (%)**	**LC (%)**	FU (mo)
Hematsu	2001	50	50-60	5-10	96-100	**66**	**94**	36
Fukumoto	2002	22	48-60	8	76.8-105	**--**	**94**	24
Hof	2003	10	19-26	1	55.1-93.6	**64**	**80**	15
Wulf	2004	20	30-37.5	3	113-162	**32**	**92**	11
Onishi	2004	35	60	10	119-131	**58**	**94**	13
McGeary	2005	47	24-72	3	60-360	**NA**	**79**	27 (T1) 19 (T2)
Zimmerman	2005	30	37.5	3	193	**75**	**87**	18
Nagata	2005	45	48	4	106	**83 (T1)** **72 (T2)**	**98**	30
Nyman	2006	45	45	3	195	**71**	**80**	43
Timmerman	**2006**	**70**	**60-66**	**3**	**180-211.2**		**95**	**17.5**
Hoyer	2006	40	45	3	195	**47**	**85**	24

Hiraoka M et al. *Cancer/Radiothérapie*. 2006;doi:10.1016/j.canrad.11.001.

Bucci

RADIATION THERAPY ONCOLOGY GROUP

RTOG 0915
(NCCTG N0927)

A RANDOMIZED PHASE II STUDY COMPARING 2 STEREOTACTIC BODY RADIATION THERAPY (SBRT) SCHEDULES FOR MEDICALLY INOPERABLE PATIENTS WITH STAGE I PERIPHERAL NON-SMALL CELL LUNG CANCER

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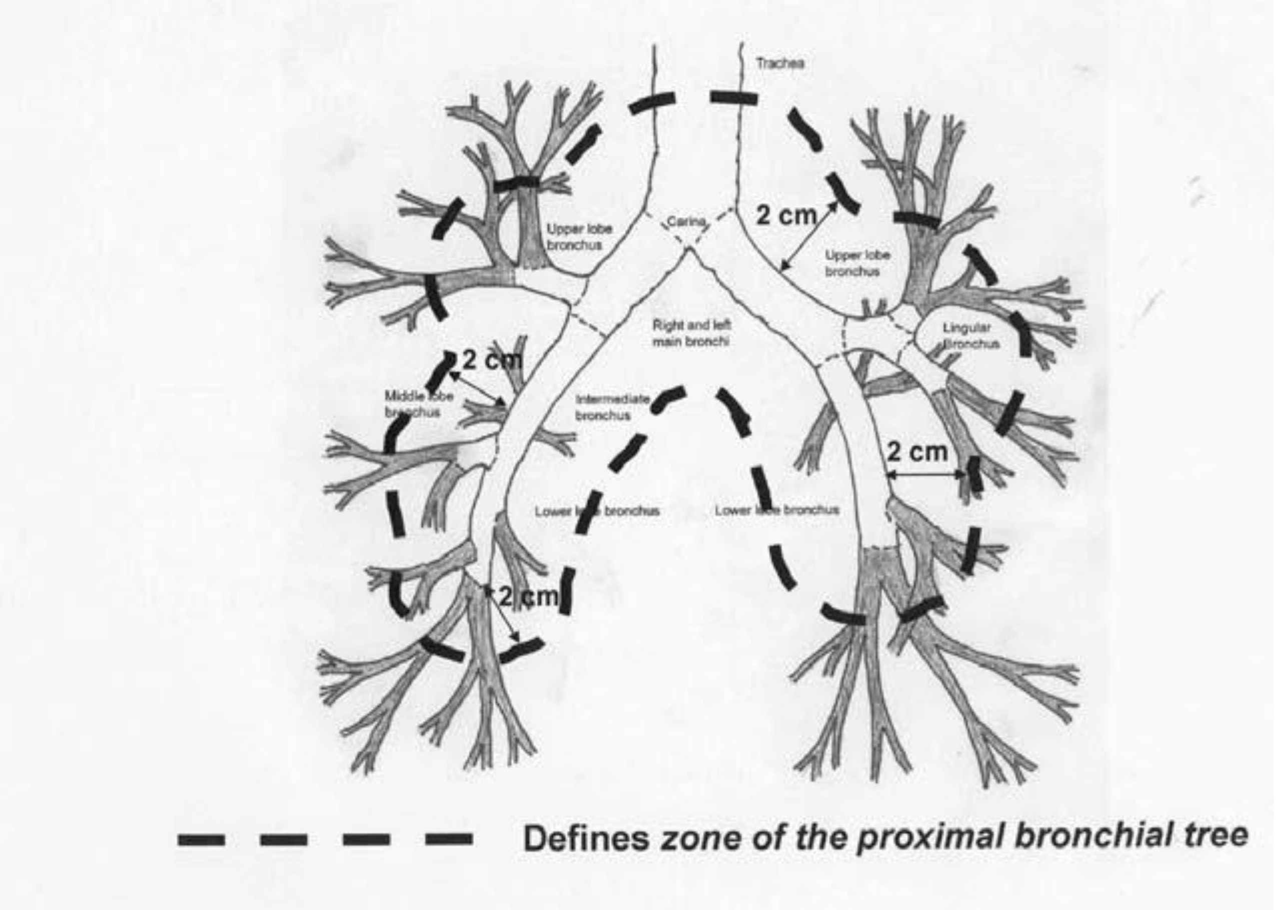
SBRT lung 2 cm exclusion zone



This is the area that the lung can act as a serial rather than parallel organ when doing SBRT

5. **<u>Intermediate Dose Spillage</u>**

The falloff gradient beyond the PTV extending into normal tissue structures must be rapid in all directions and meet the following criteria:

a. *Location*

The maximum total dose over all fractions in Gray (Gy) to any point 2 cm or greater away from the PTV in any direction must be no greater than D_{2CM} where D_{2CM} is given by the table below.

b. *Volume*

The ratio of the volume of the 34 or 12 Gy isodose volume to the volume of the PTV must be no greater than $R_{50\%}$ where $R_{50\%}$ is given by the table below. This

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

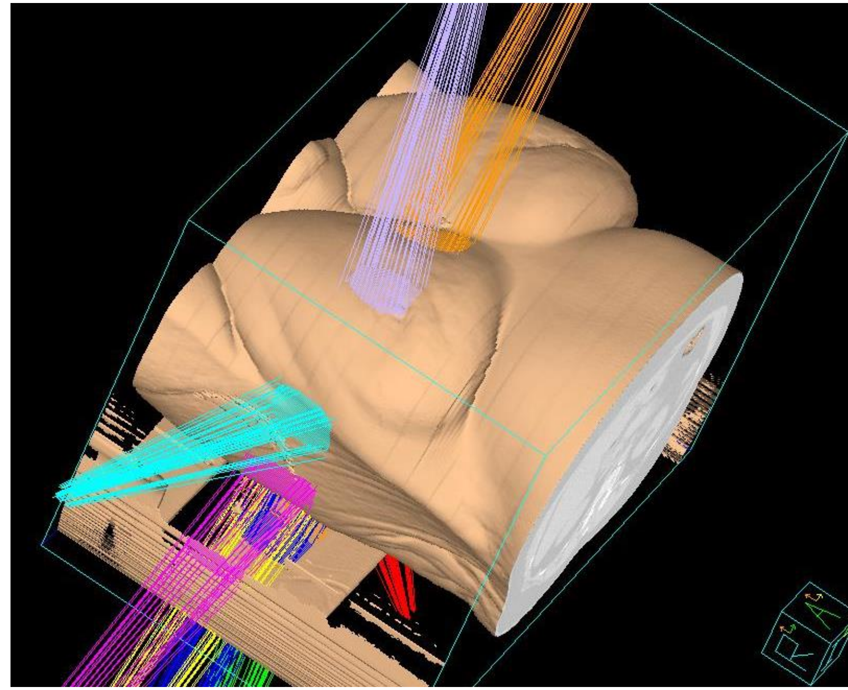
PTV Volume (cc)	Ratio of Prescription Isodose Volume to the PTV Volume		Ratio of 50% Prescription Isodose Volume to the PTV Volume, $R_{50\%}$		Maximum Dose (in % of dose prescribed) @ 2 cm from PTV in Any Direction, D_{2cm} (Gy)		Percent of Lung Receiving 20 Gy Total or More, V_{20} (%)	
	Deviation		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.

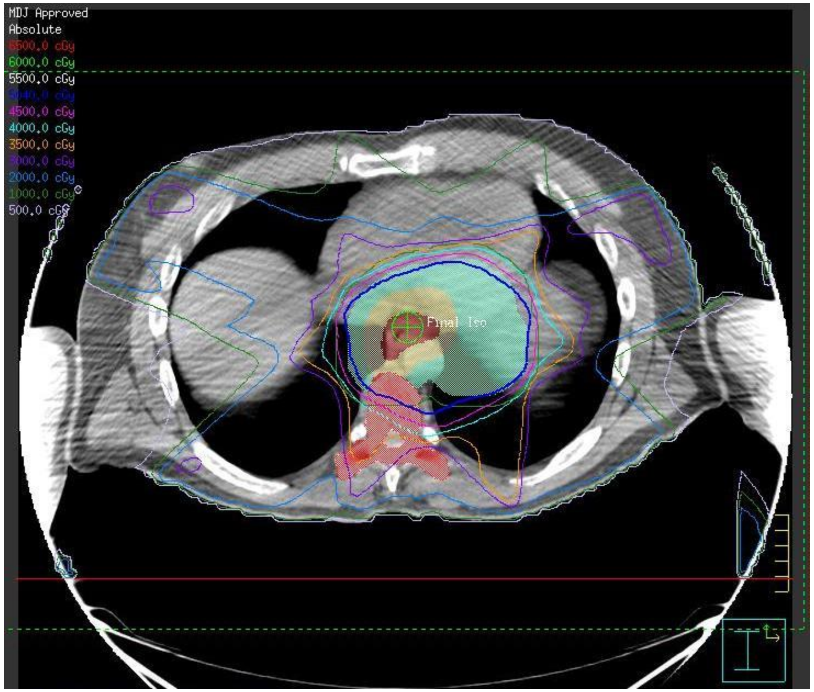
Note 2: Protocol deviations greater than listed here as “minor” will be classified as “major” for protocol compliance (see Section 6.7).

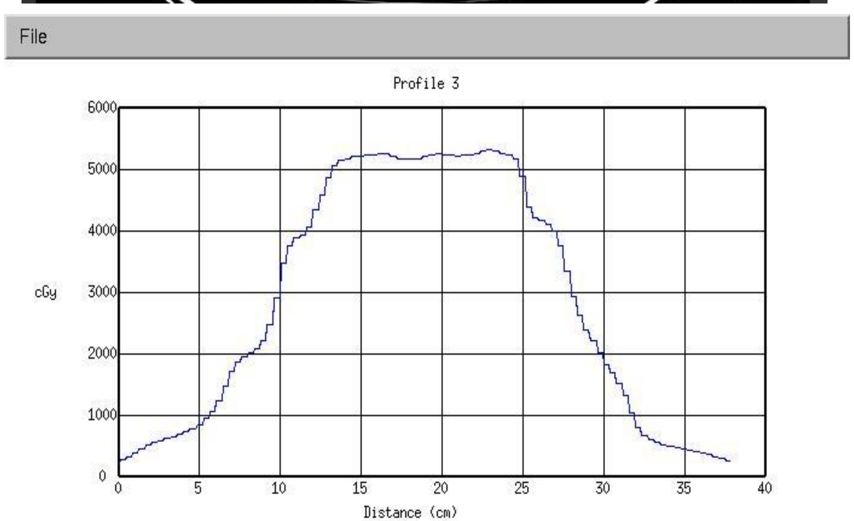
Treatment Planning

- *3D planning with a large number of beams (little benefit to IMRT and some challenges)*
- *Typically use 6 to 9 non coplanar beams*
- *Tight block margins for better falloff at the expense of homogeneity in the target*

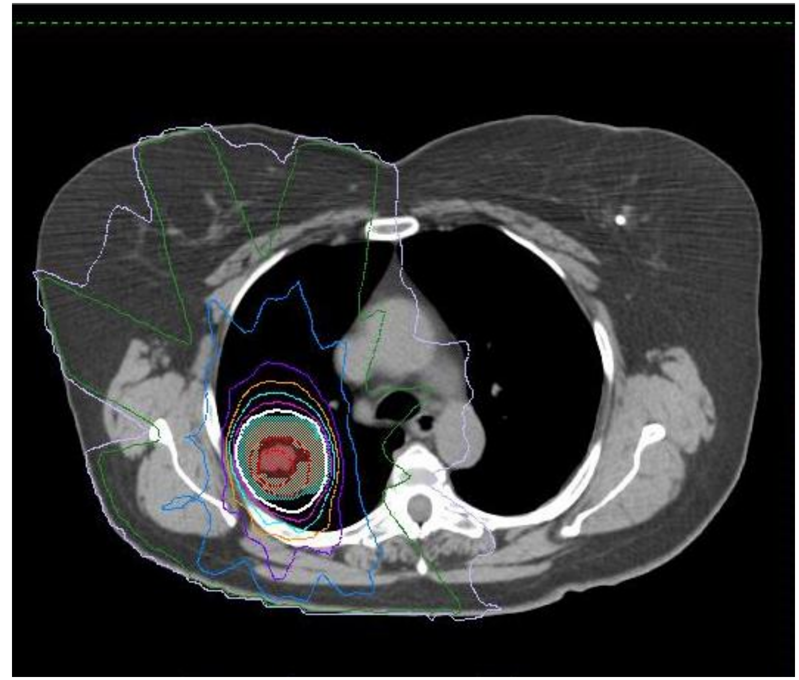


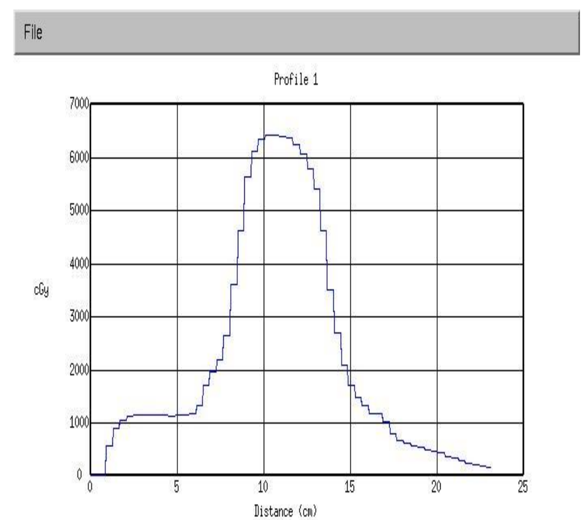
Typical XRT Plan

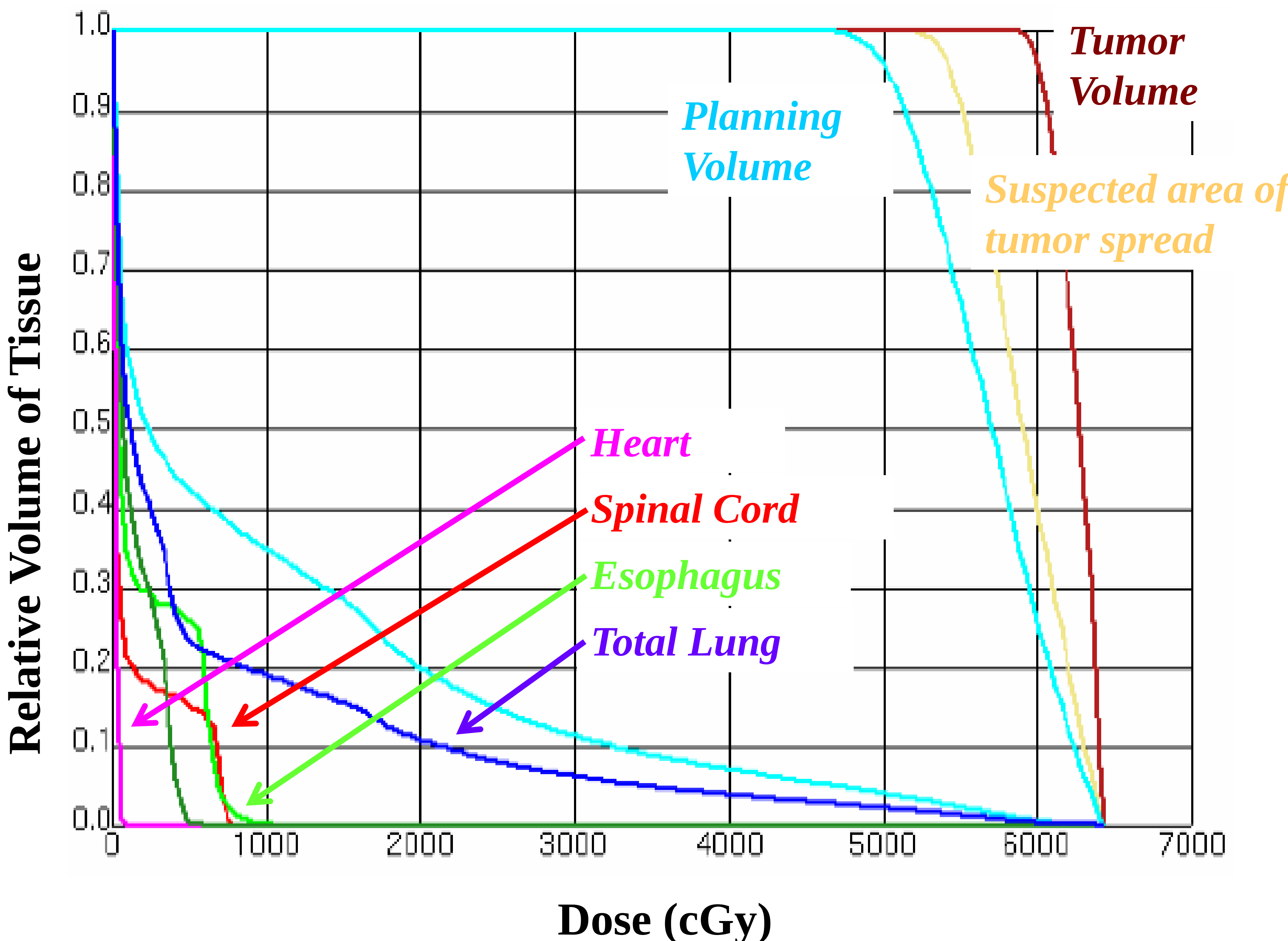




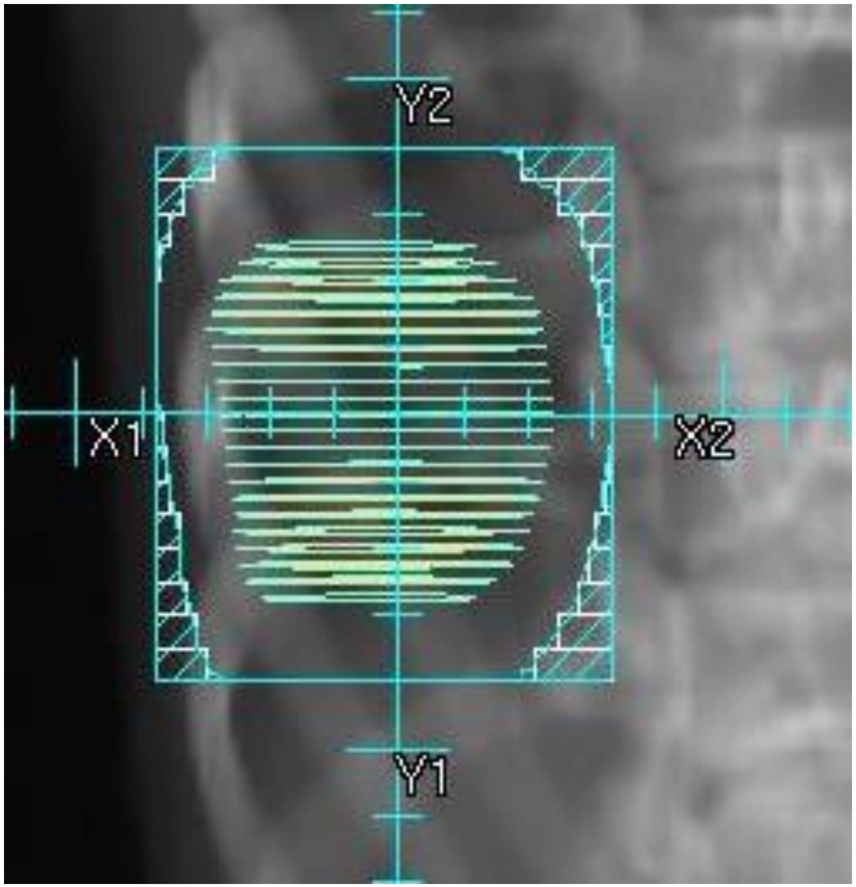
Typical SBRT Plan



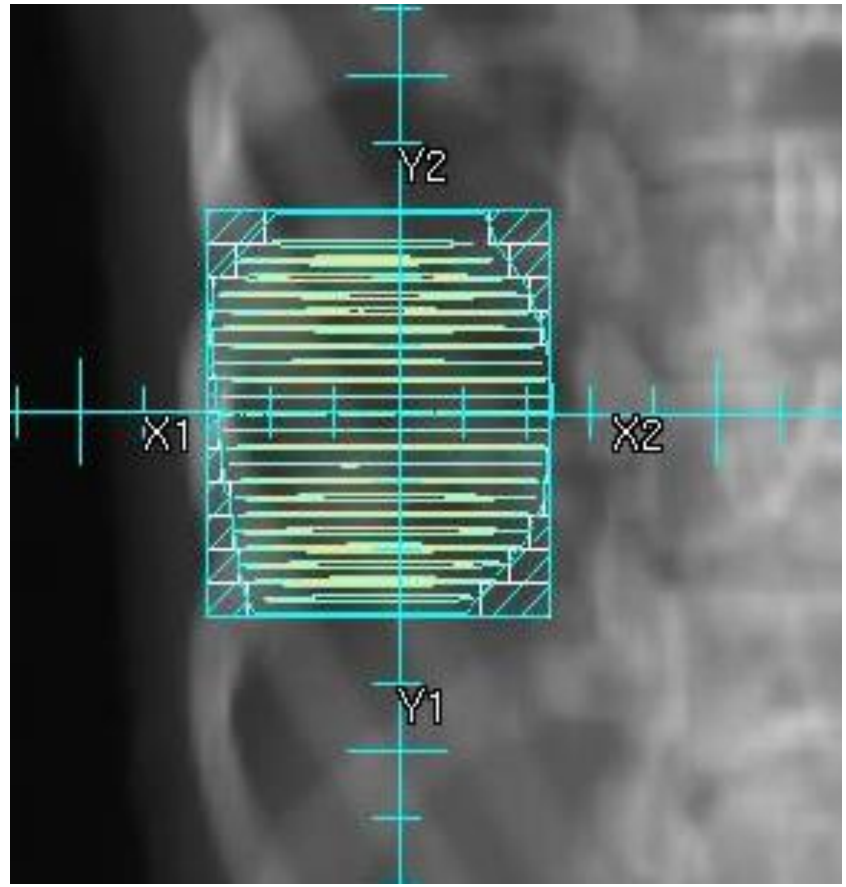



Tumor Volume
Planning Volume
Suspected area of tumor spread
Heart
Spinal Cord
Esophagus
Total Lung
Relative Volume of Tissue
Dose (cGy)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1000
2000
3000
4000
5000
6000
7000

One method of achieving sharp falloff is tight blocking



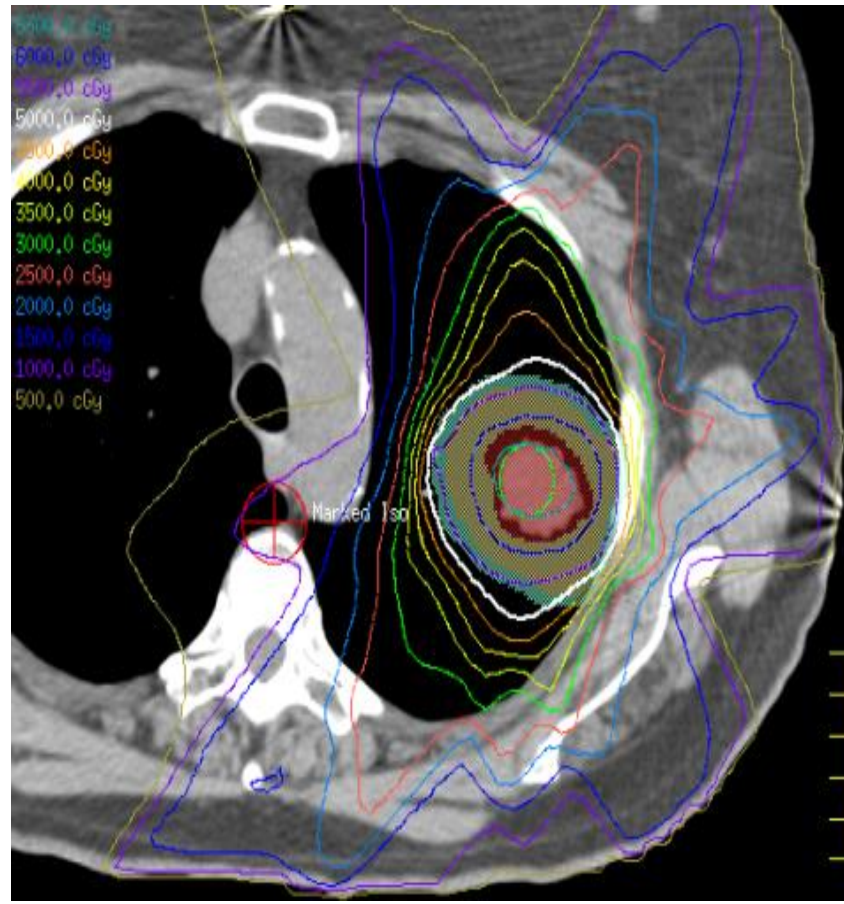
Block Margin



No Margin

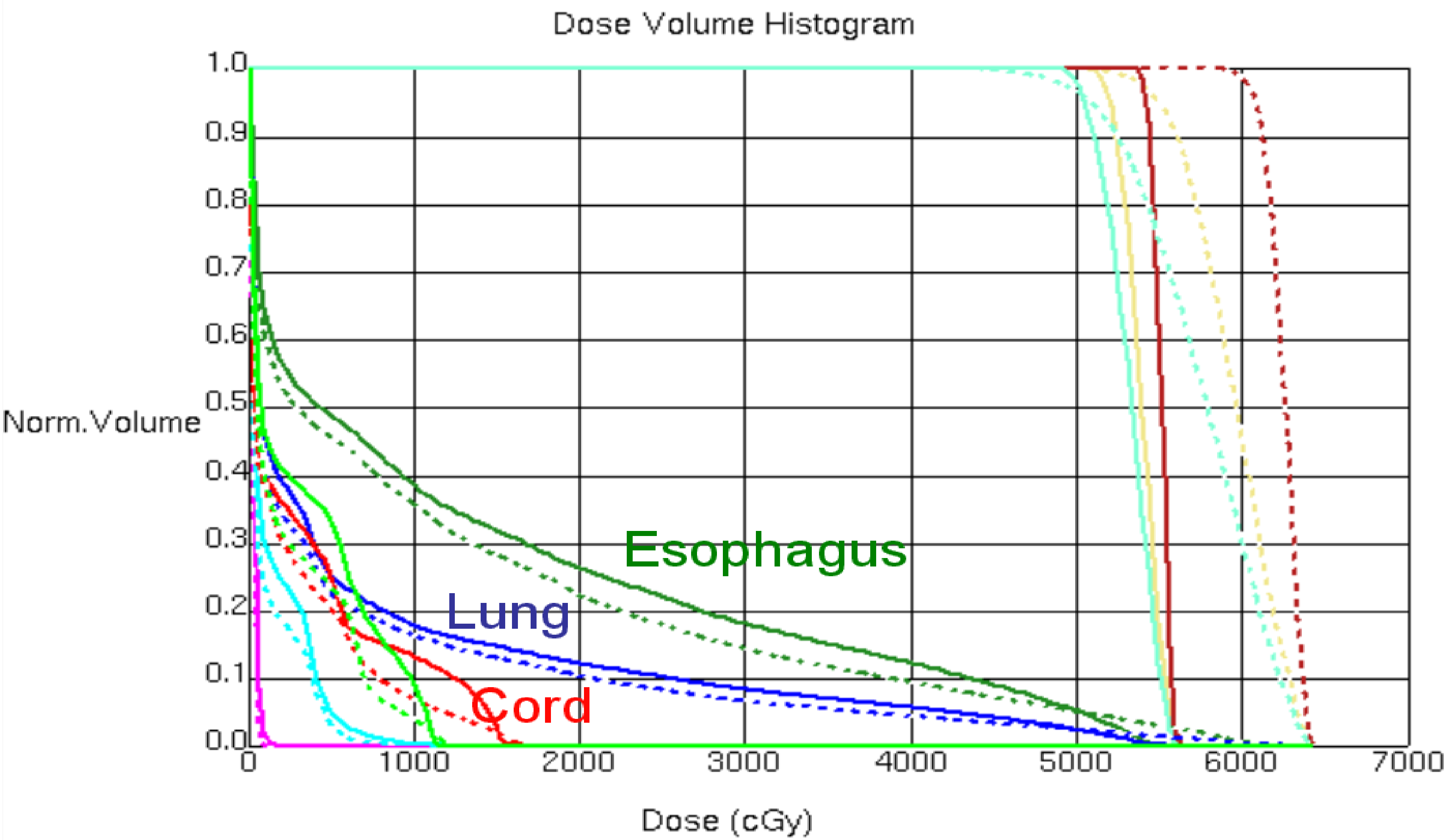
Brooks

Blocking
Conventional vs. No Margin



Brooks

DVH Blocking Comparison

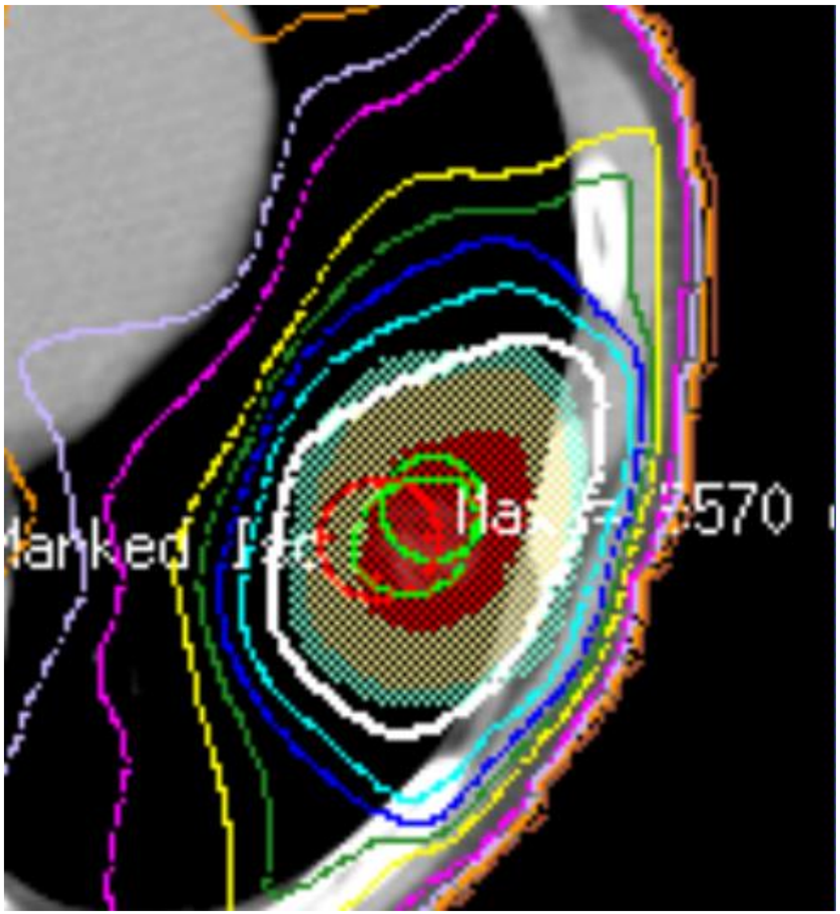


Dashed= No Blk Margin Solid= Conventional

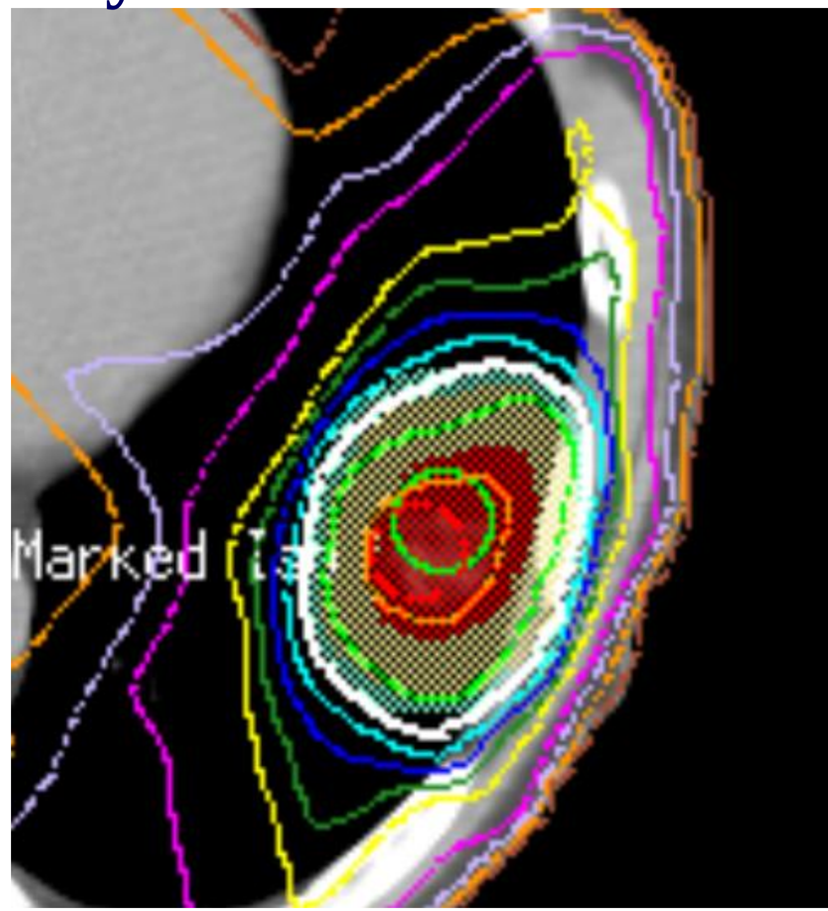
Brooks

No Margin Skin and Structure Benefits

Yellow 35Gy



Conventional Block Margins



No Block Margins

Brooks

Planning issue with SBRT

- Calculation Algorithms
- Homogeneous vs Heterogeneous
- Avoidance structures and dose limits
- Non-coplaner beams and collision

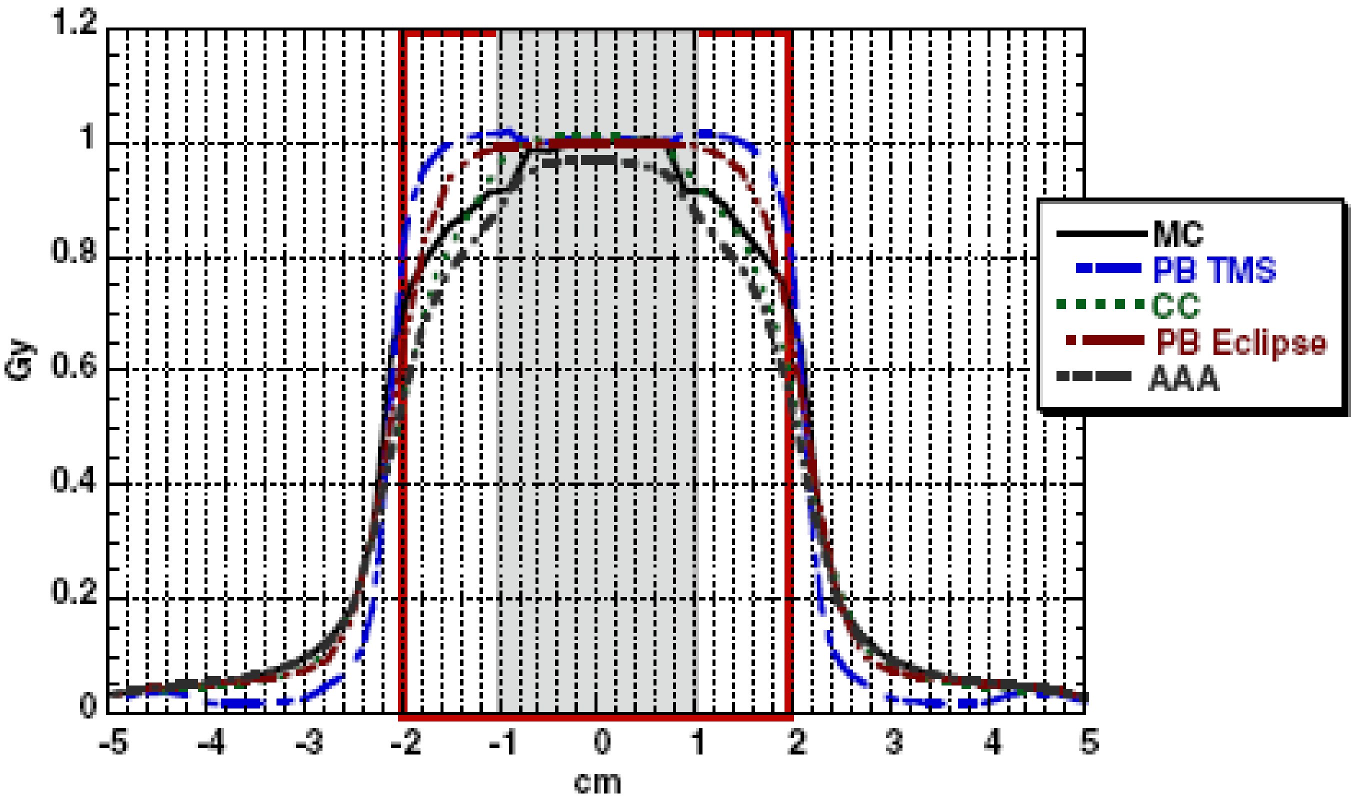
SBRT of lung tumours: Monte Carlo simulation with PENELOPE of dose distributions including respiratory motion and comparison with different treatment planning systems

Vanessa Panettieri[1,2], Berit Wennberg[2], Giovanna Gagliardi[2], Maria Amor Duch[1], Mercè Ginjaume[1] and Ingmar Lax[2]

[1] Institut de Tècniques Energètiques, Universitat Politècnica de Catalunya, Diagonal 647, 08028 Barcelona, Spain
[2] Department of Hospital Physics, Karolinska University Hospital and Karolinska Institutet, Stockholm, Sweden

Panettieri et al

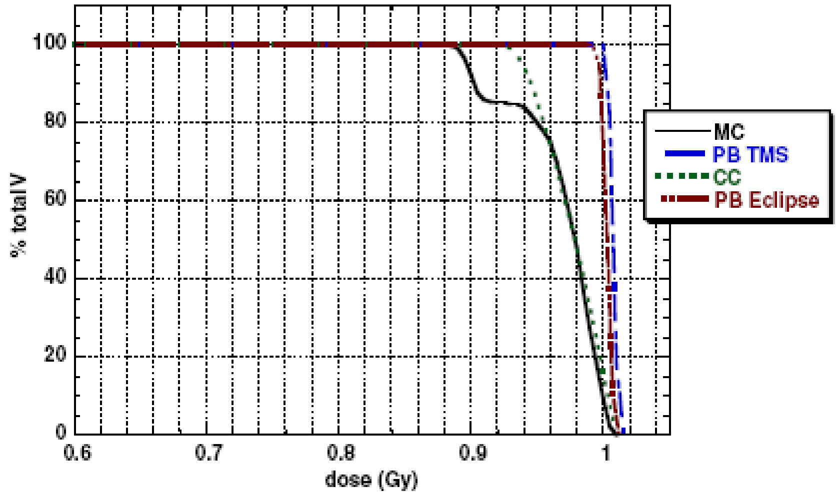
If we take Monte-Calro to be the truth then only CC (Collapsed Cone convolution) does a good job estimating dose at the periphery of the PTV, AAA is not bad. Pencil beam is not appropriate for planning these treatments.



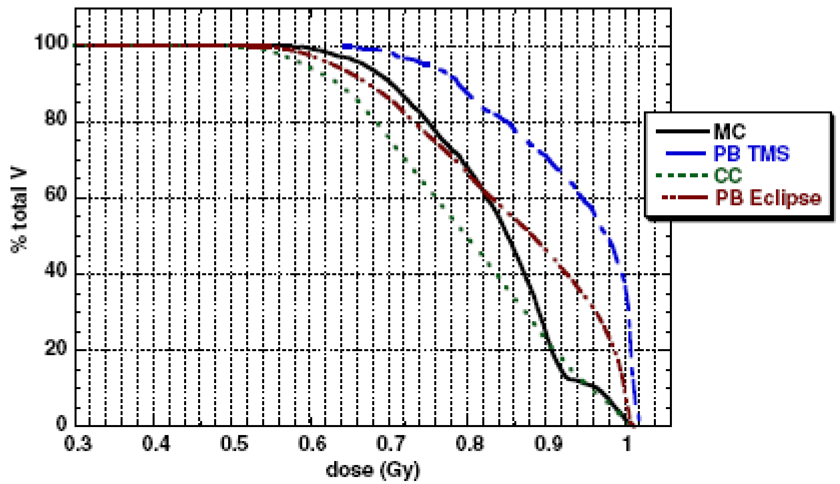
(a) y profile 2 cm 1 cm margin

Panettieri et al

DVHs for GTV and PTV



(a) GTV 2 cm



(c) PTV 2 cm

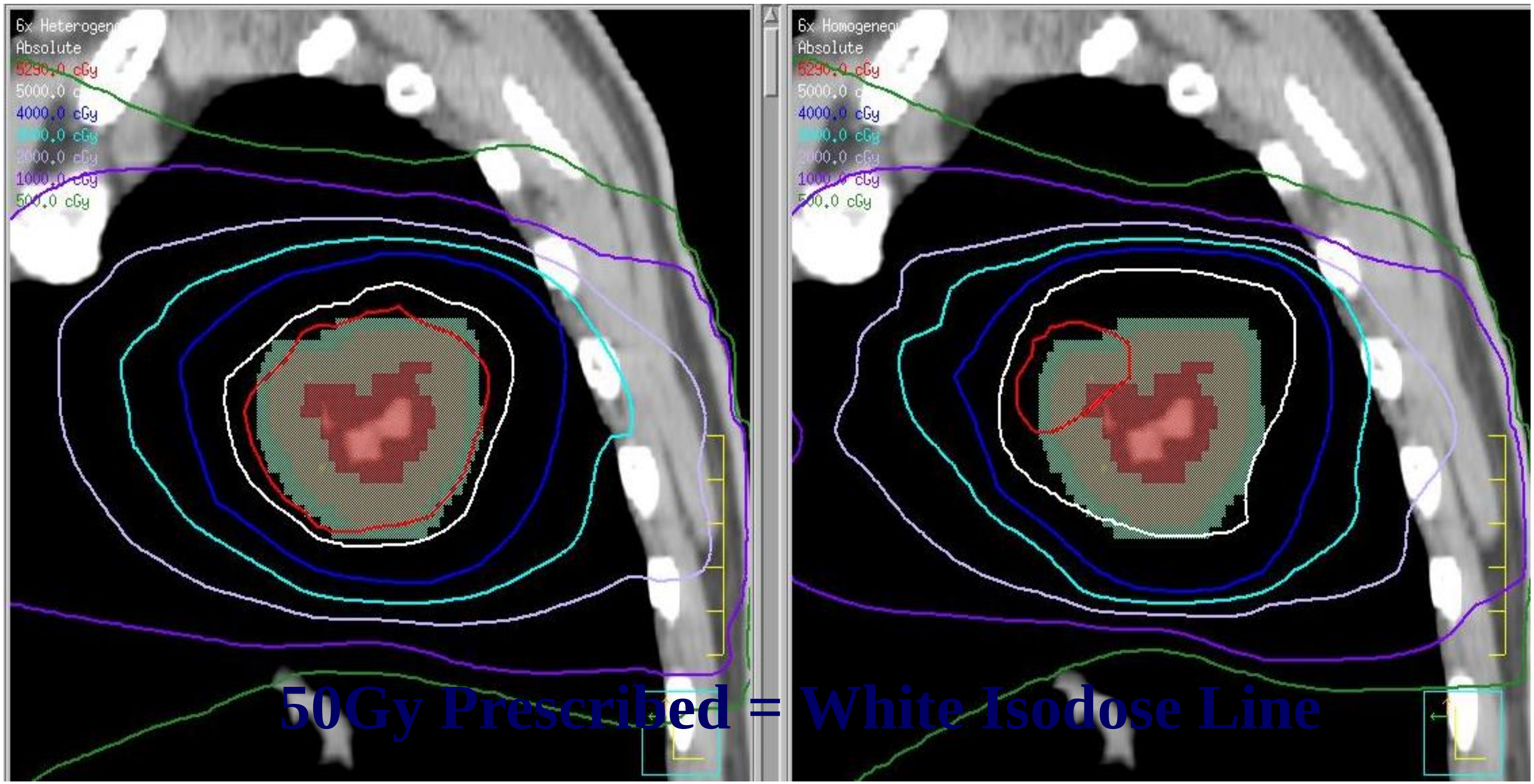
- The GTV coverage is still not so bad (only 10 % under dose)
- The PTV/CTV (in-lung) is more complicated.

Panettieri et al

Homogenous planning is not the solution

- Can greatly underestimate tumor coverage
- Rewards high energy beams in lung
  - This is a bad thing
- The ratio of the calculated to delivered dose will be a function of tumor size and location

Treatment Planning
Caution with Homogeneous Planning



50Gy Prescribed = White Isodose Line

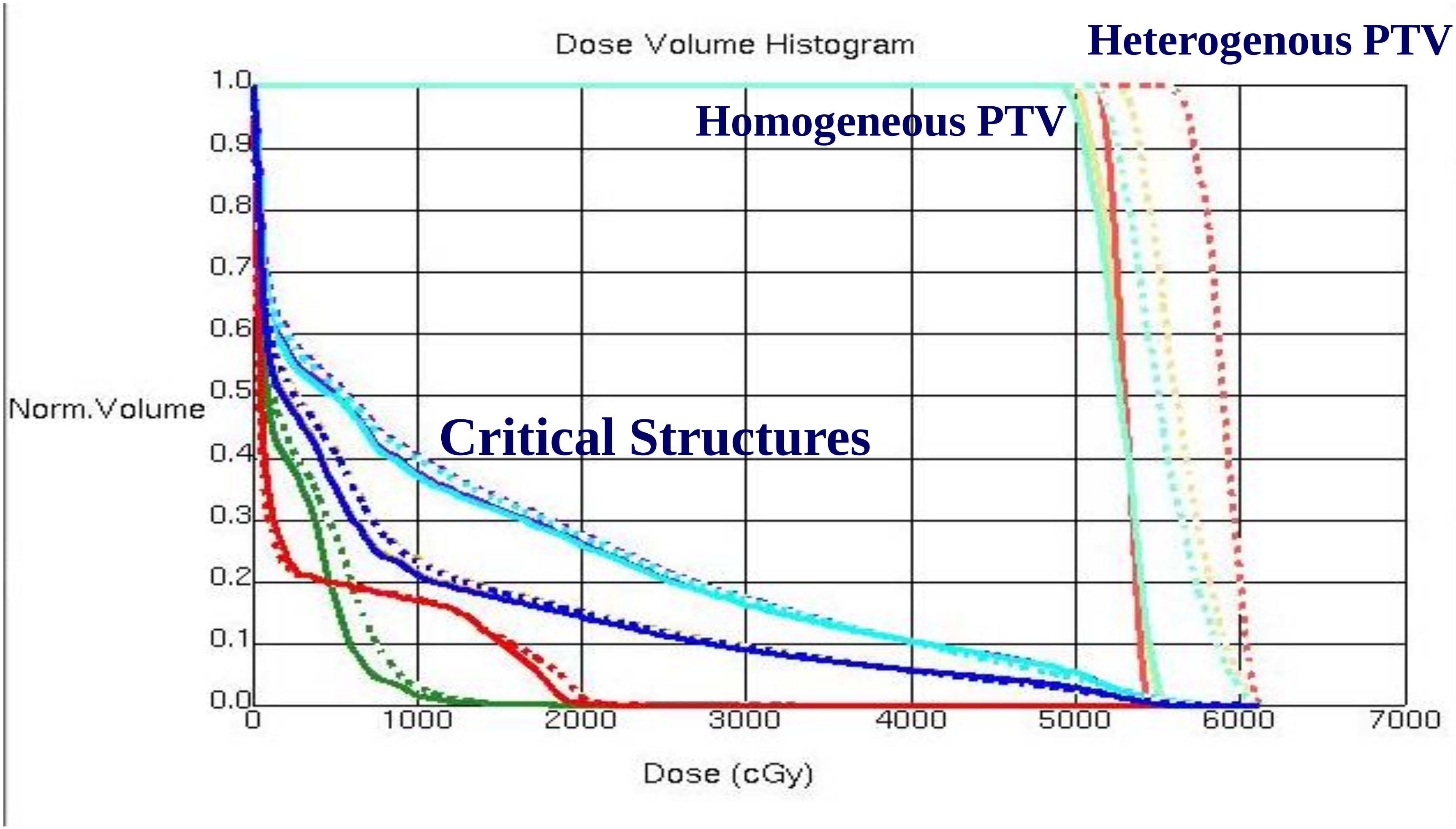
Heterogeneous 6X with MU plugged in from Homogeneous 6X

Homogeneous 6X

Brooks

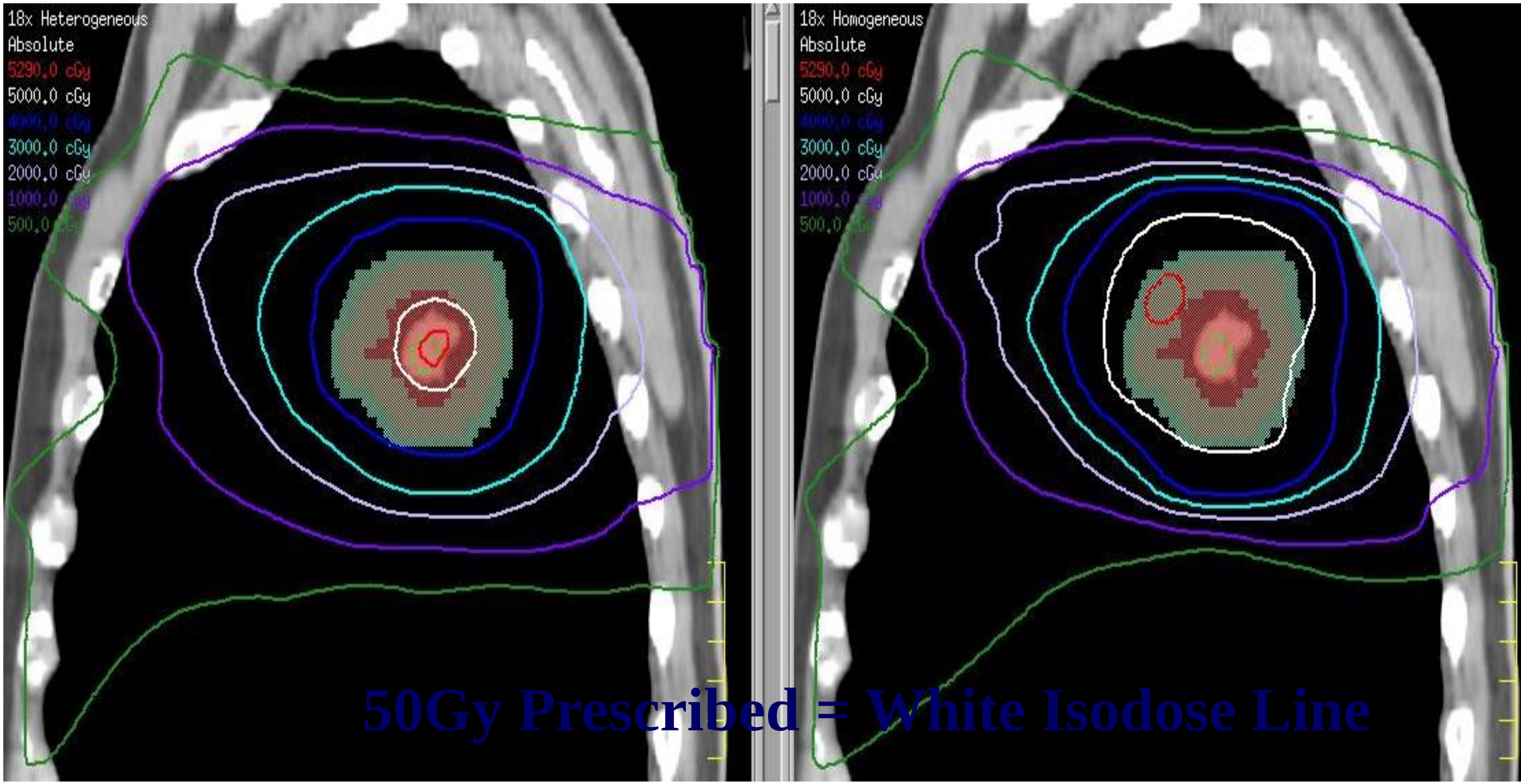
Treatment Planning

Caution with Homogeneous Planning



SOLID: Homogeneous 6X **DASHED: Heterogeneous 6X** *Brooks*

Treatment Planning
Caution with Homogeneous Planning



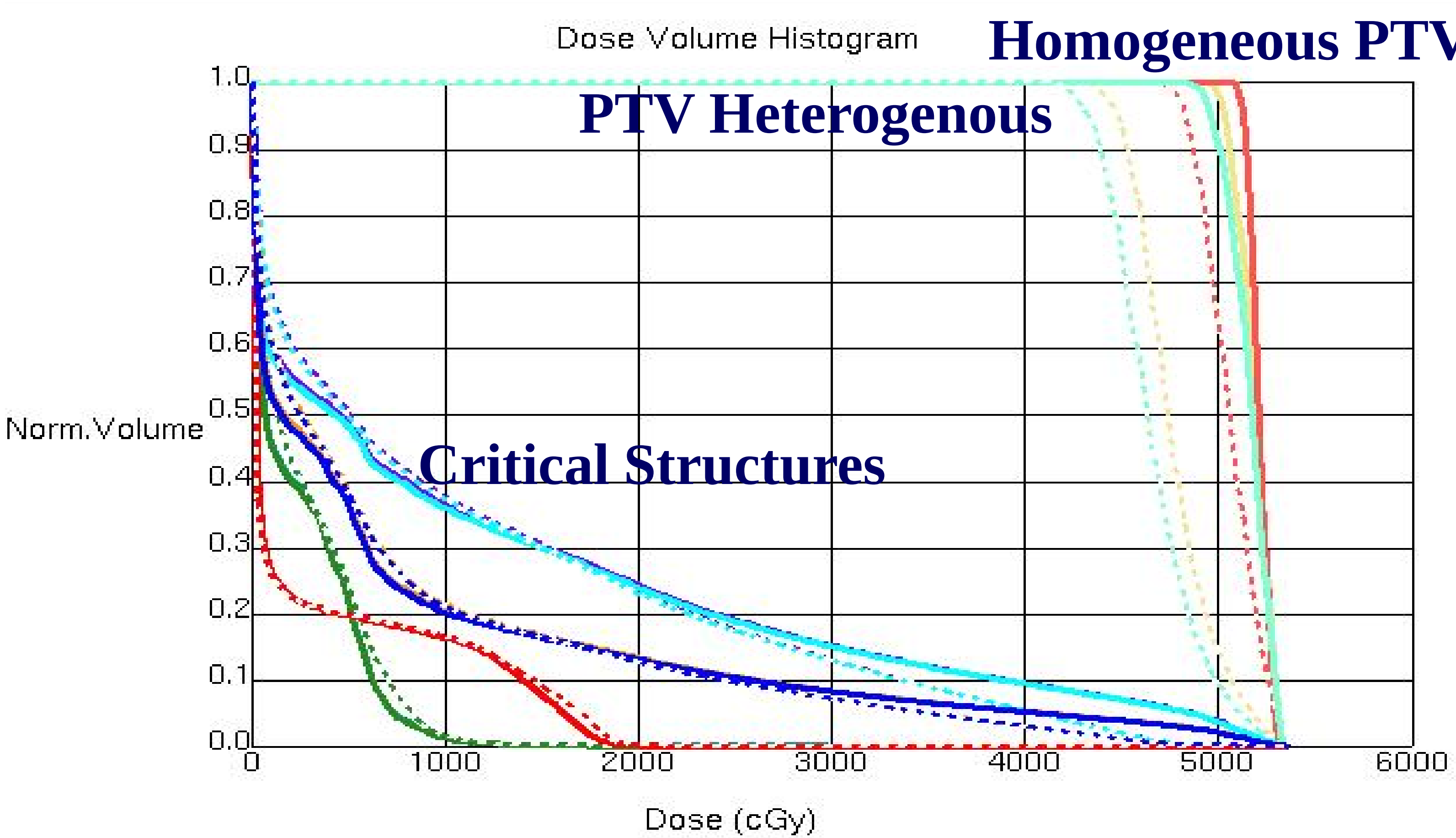
50Gy Prescribed = White Isodose Line

Heterogeneous 18X with MU plugged in from Homogeneous 18X

Homogeneous 18X

Brooks

Treatment Planning
Caution with Homogeneous Planning



SOLID: Homogeneous 18X **DASHED: Heterogeneous 18X**

Brooks

VMAT Comparison SBRT Case Example RTOG 0915 34Gy x 1

Clinical SBRT (used)

- 11 beams – 2 non coplanar
- Planning time (3 hours)
- Total MU: 8548
- Delivery time: 23 minutes

Approved | Machine | O

Name	Couch	Gantry Start	Gantry Stop
RPO Lung	0	220	220
RPO2 Lung	0	260	260
RAO Lung	0	300	300
RAO2 Lung	0	340	340
LAO Lung	0	20	20
LAO2 Lung	0	60	60
LPO Lung	0	100	100
LPO2 Lung	0	140	140
PA Lung	0	180	180
Rt Cephelic	30	270	270
Caudal	90	30	30

SmartArc (Planning Study)

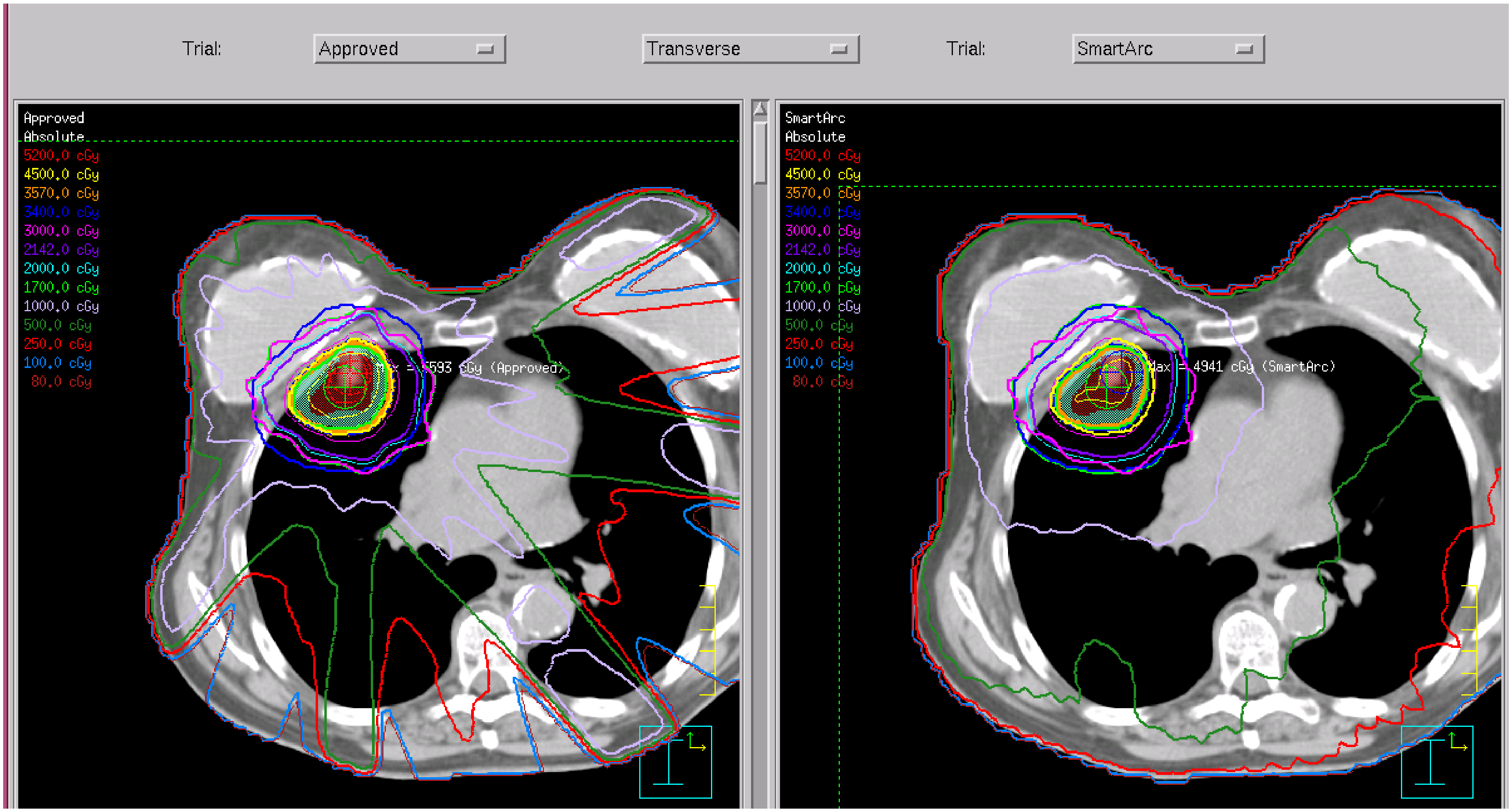
- 2 Arcs coplanar
- Planning Time (30 minutes)
- Total MU: 7969
- Estimated delivery time 12 minutes

SmartArc | Machine | C

Name	Couch	Gantry Start	Gantry Stop
Beam_1	0	181	180
Beam_1_2	0	180	181

Comparison: SBRT Case

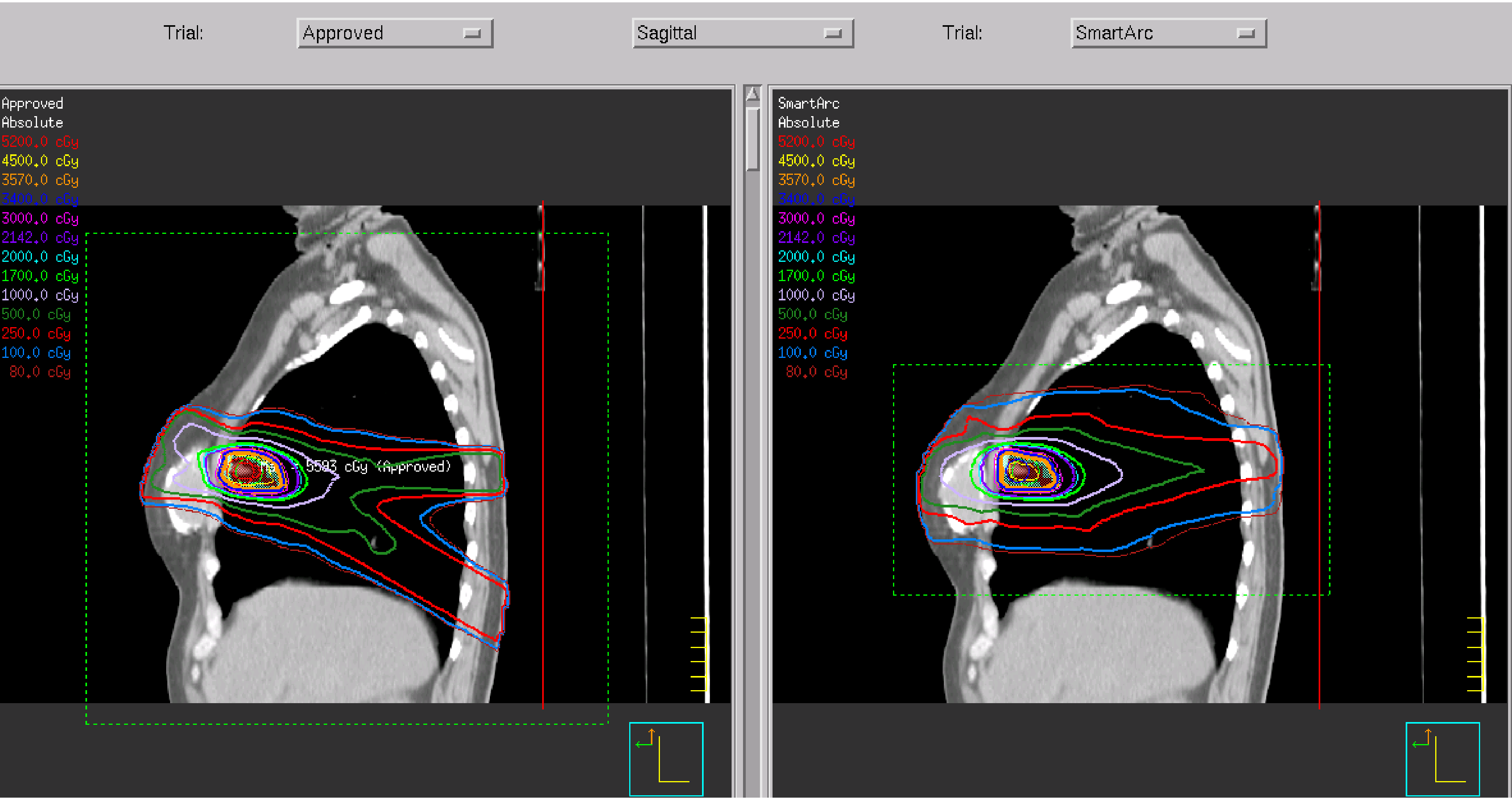
Clinical SBRT Plan *SmartArc Plan*



Comparison: SBRT Case

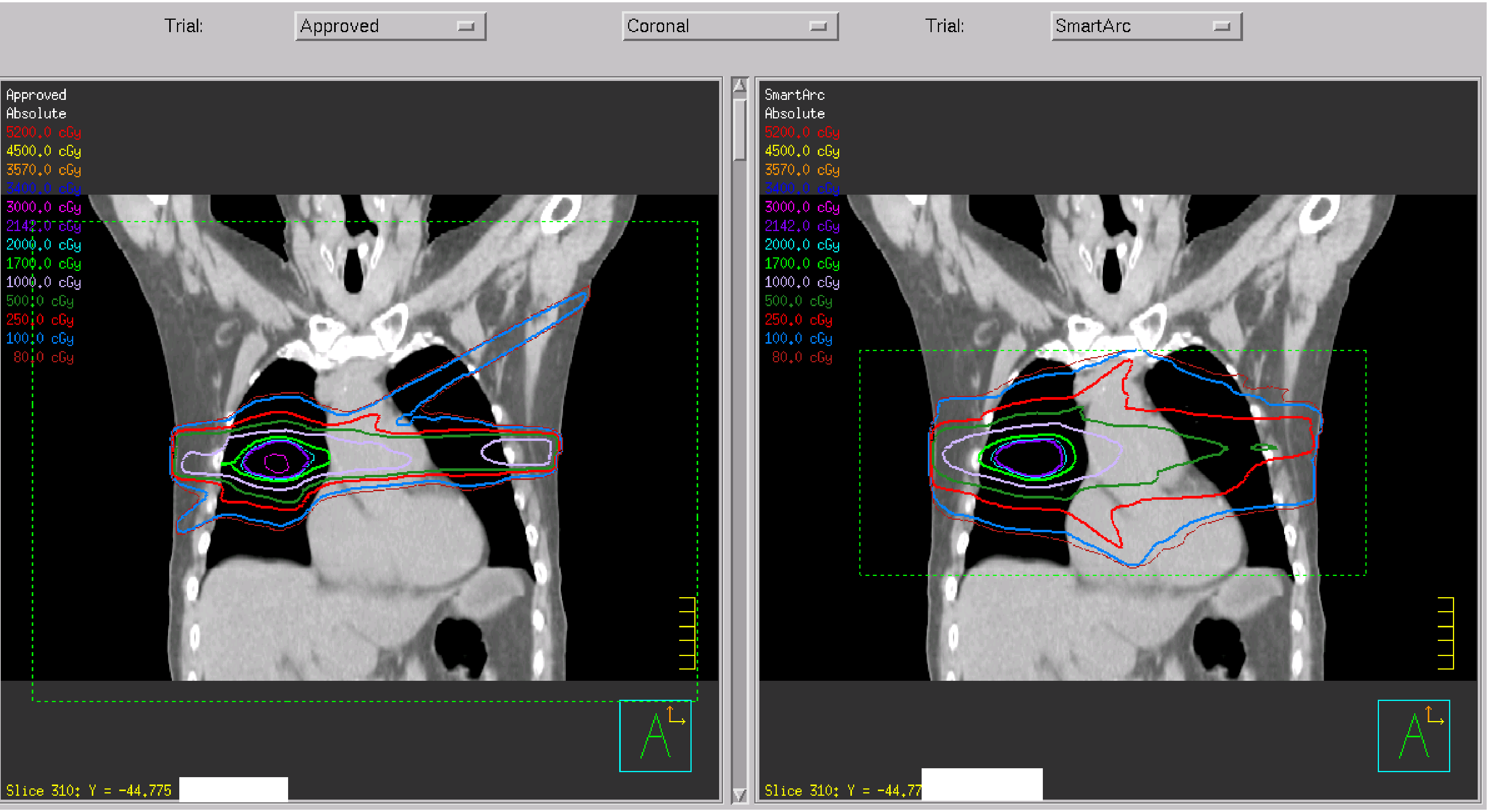
Clinical SBRT Plan

SmartArc Plan



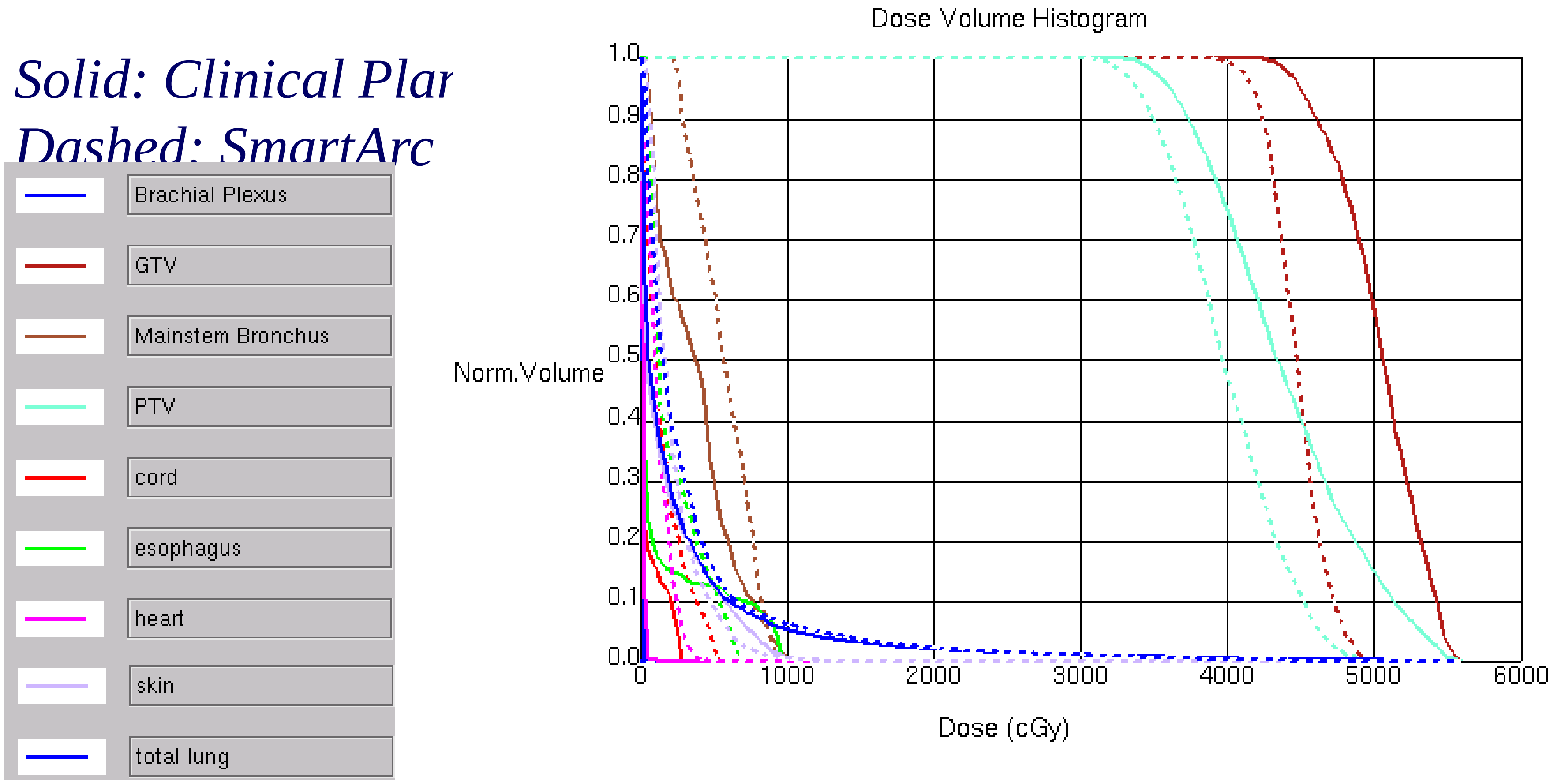
Comparison: SBRT Case

Clinical SBRT Plan   SmartArc Plan



Comparison: SBRT Case

Solid: Clinical Plar
Dashed: SmartArc



Both plans meet the RTOG 0915 Guidelines for 34 Gy in 1 fx

SBRT OAR Guidelines

SBRT is an ablative procedure: Care must be taken to control normal tissue toxicity

OAR Guideline should be:

1) A function of the number of fractions

2) Based on published guidelines based on heterogeneous calculations when ever possible

3) Lower than traditional fractionation

4) Updated based on follow-up

STEREOTACTIC BODY RADIATION THERAPY IN CENTRALLY AND SUPERIORLY LOCATED STAGE I OR ISOLATED RECURRENT NON–SMALL-CELL LUNG CANCER

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Departments of *Radiation Oncology, †Radiation Physics, and §Thoracic and Cardiovascular Surgery, The University of Texas M. D. Anderson Cancer Center, Houston, TX

Table 1. Critical organ dose–volume limits for central and superior non–small-cell lung cancer lesions using stereotactic body radiation therapy to deliver 50 Gy in four fractions

Organ	Volume, mL	Total dose (dose per fraction), Gy
Esophagus	≤1	35 (8.8)
	≤10	30 (7.5)
Brachial plexus*	Any point	<40
	≤1	35 (8.8)
	≤10	30 (7.5)
Trachea	≤1	35 (8.8)
	≤10	30 (7.5)
Main bronchus and bronchial tree	≤1	40 (10)
	≤10	35 (8.8)
Heart	≤1	40 (10)
	≤10	35 (8.8)
Whole lung (right & left, excluding gross tumor volume)	V20 Gy	<20%
	V10 Gy	<30%
	V5 Gy	<40%
Major vessels	≤1	40 (10)
	≤10	35 (8.8)
Skin (to 5 mm)	≤1	40 (10)
	≤10	35 (8.8)
Spinal cord	≤1	20 (5)
	≤10	15 (3.8)

* Added after a case of neuropathy, as shown in Fig. 3.

Tolerance Doses

Conventional 60-66Gy 30-33 fractions Chemo included		SBRT using 50Gy in 4 fractions	
Structures	Tolerance	Structures	Tolerance
Spinal Cord	<45Gy	Spinal Cord	<20Gy
Esophagus	55Gy (<50%) Dmax75Gy	Esophagus	40Gy <1cc, 35Gy <10cc
Trachea	55Gy (<50%) Dmax75Gy	Trachea	40Gy <1cc, 35Gy <10cc
Main bronchus	55Gy (<50%) Dmax75Gy	Main bronchus	45Gy <1cc, 40Gy <10cc
Heart	V40<50%	Heart	45Gy <1cc, 40Gy <10cc
Brachial Plexus	Dmax70Gy	Brachial Plexus	45Gy <1cc, 40Gy <10cc
Vessels	Dmax70Gy	Vessels	45Gy <1cc, 40Gy <10cc
Skin	60Gy	Skin	40Gy <1cc, 35Gy <10cc
Lung	MLD<20Gy, V20<35%	Lung	MLD<8.5Gy, V20<20%

Brooks

Tolerance Doses

RTOG (L-0236) SBRT 60Gy in 3 fractions		SBRT using 50Gy in 4 fractions	
Structures	Tolerance	Structures	Tolerance
Spinal Cord	18Gy	Spinal Cord	<20Gy
Esophagus	27Gy	Esophagus	40Gy <1cc, 35Gy <10cc
Trachea	30Gy	Trachea	40Gy <1cc, 35Gy <10cc
Main bronchus	30Gy	Main bronchus	45Gy <1cc, 40Gy <10cc
Heart	30Gy	Heart	45Gy <1cc, 40Gy <10cc
Brachial Plexus	24Gy	Brachial Plexus	45Gy <1cc, 40Gy <10cc
Vessels	30Gy	Vessels	45Gy <1cc, 40Gy <10cc
Skin	D2cm Table 28-40Gy	Skin	40Gy <1cc, 35Gy <10cc
Lung	V20<10% 10-15%Minor	Lung	MLD<8.5Gy, V20<20%

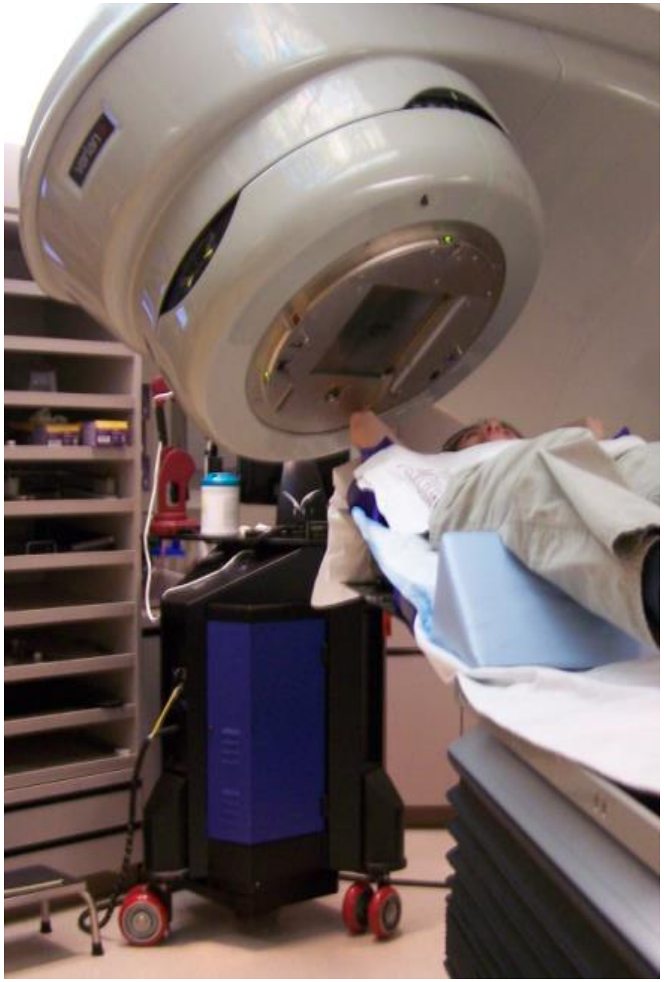
Non-Coplanar - Treatment Beams

- More beams = lower maximum skin dose
- Less beams = lower lung V10, V5
- Trade off depends on tumor location

Non-Coplanar beam require careful consideration of collisions

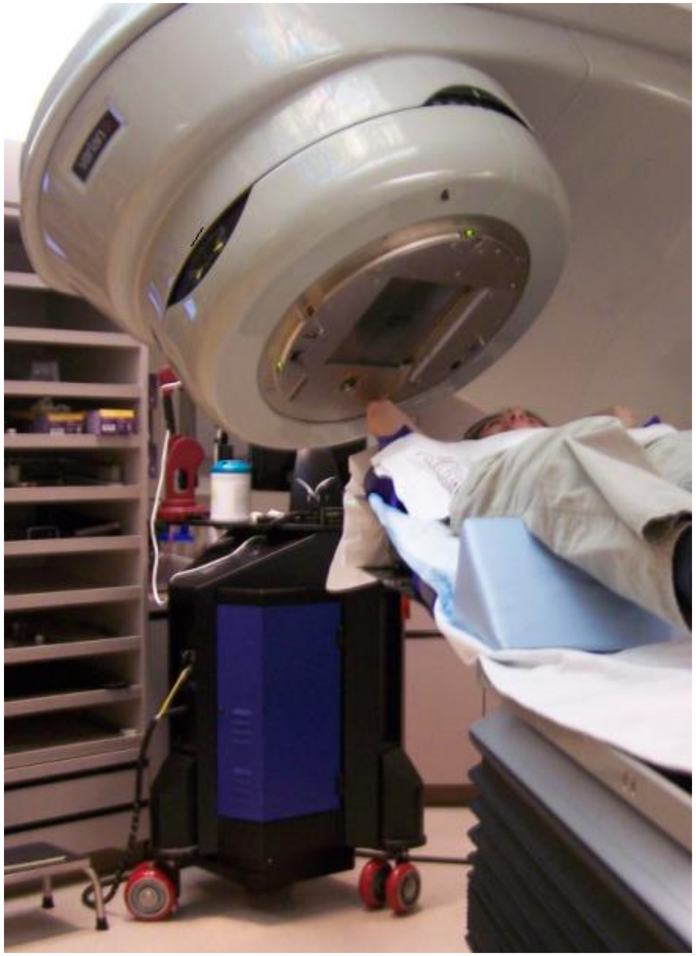
Deliverable beams are a function of
- •Isocenter position
- •Arm position
- •Patient position on couch
- •Machine geometry

Dry-runs are strongly recommended to ensure all beams can be delivered



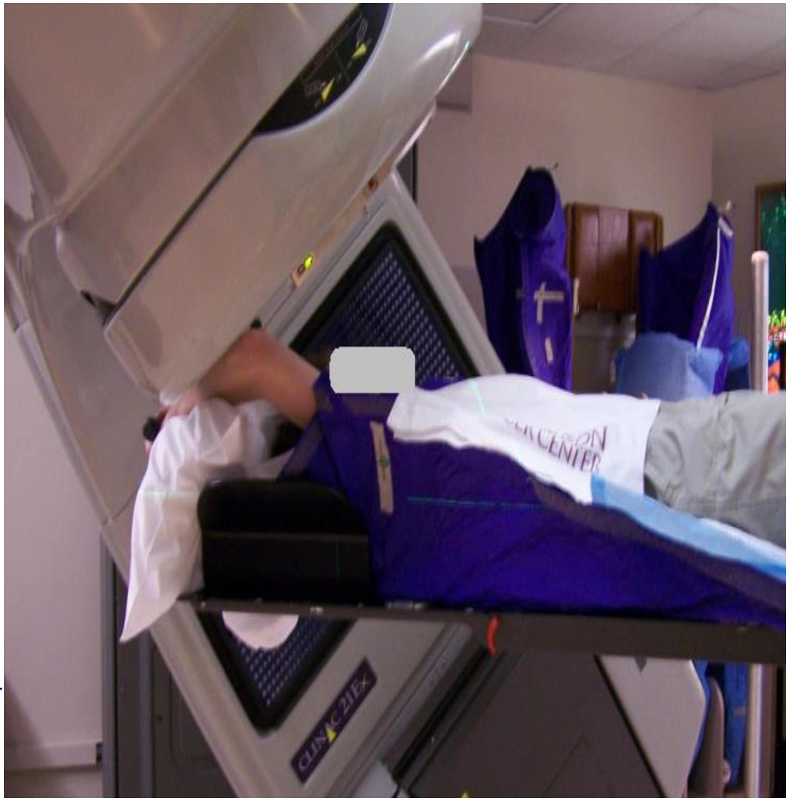
Dry-run / collision check

- On the first fraction treatment is optional
  - After alignment all beams angles are checked to ensure there are no collisions between the patient and the gantry
  - A treatment order is developed including angles that require the RTTs to enter the room.



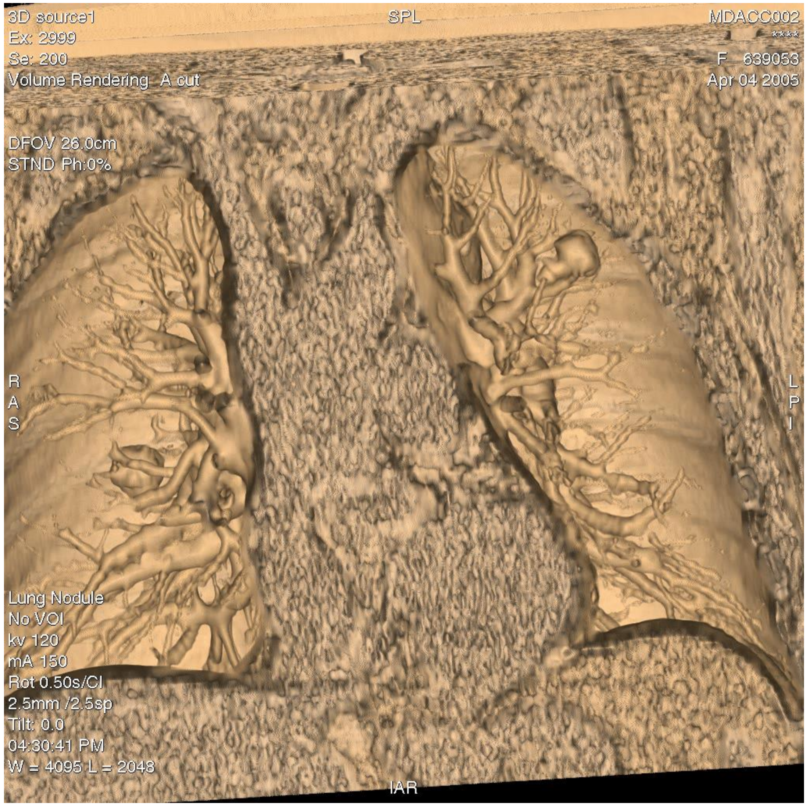
Dry-run / collision check

- On the first fraction treatment is optional
  - The patient can reject treatment until better pain management can be provided (arms above head)
  - The physicists, RTTs and attendings have the opportunity to not treat if they have any concerns about anything in the plan or the patient setup.

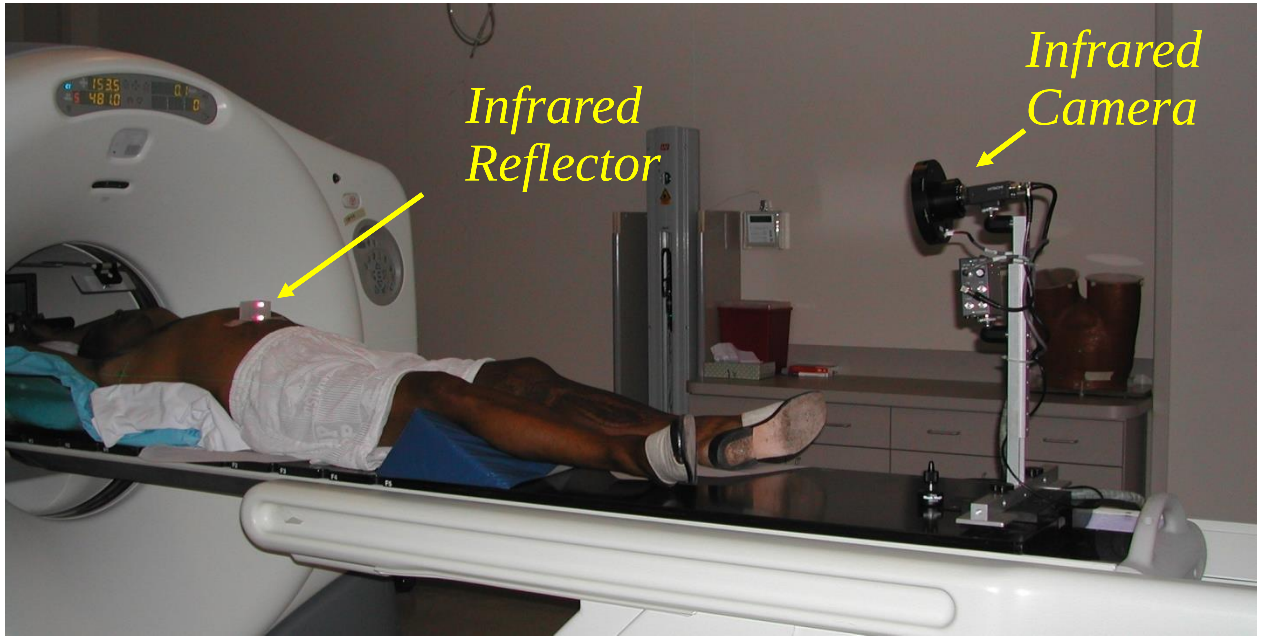


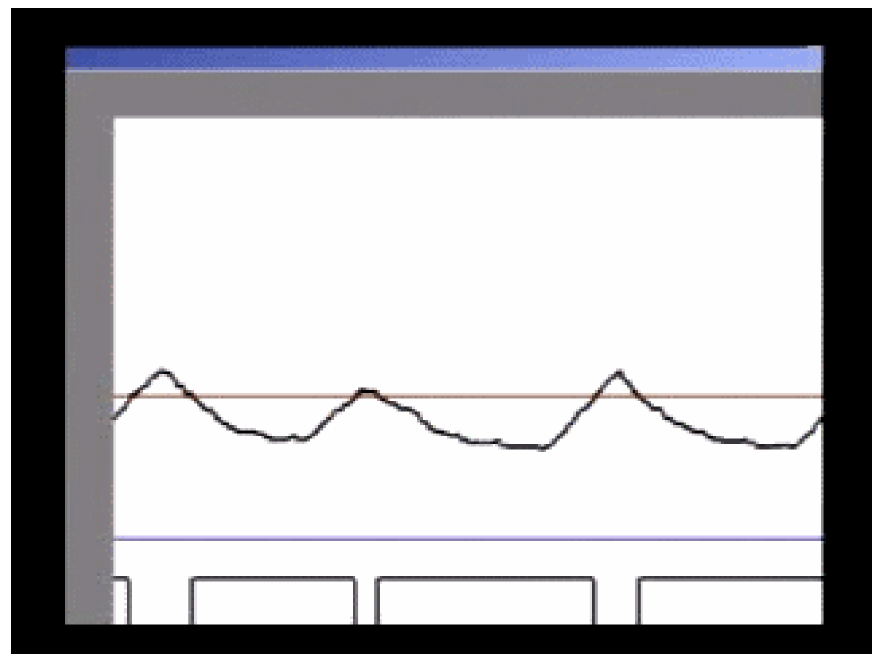
motion management and set-up

- The sharp dose gradients require good knowledge of the tumor location and motion at the time of planning and treatment.
- Thoracic tumors can move up to 2 cm with respiration (0.5- 1.0 cm typical)
- Respiratory motion management is used to obtain a planning dataset including the path of tumor motion during treatment.
- Daily in-room imaging is used to minimize setup uncertainties.



4DCT





Accounting for tumor motion

- Past:
  - Surround CTV with generic margin to allow for tumor motion
- Current:
  - ITV: Customized treatment margins and techniques for each patient based on 4D imaging.
  - Dynamic Gating: Gate the treatment over a limited number of phases of the respiratory cycle
  - Breath-hold Gating: Eliminate motion by immobilizing the tumor
  - Tumor tracking: move the beam with the tumor

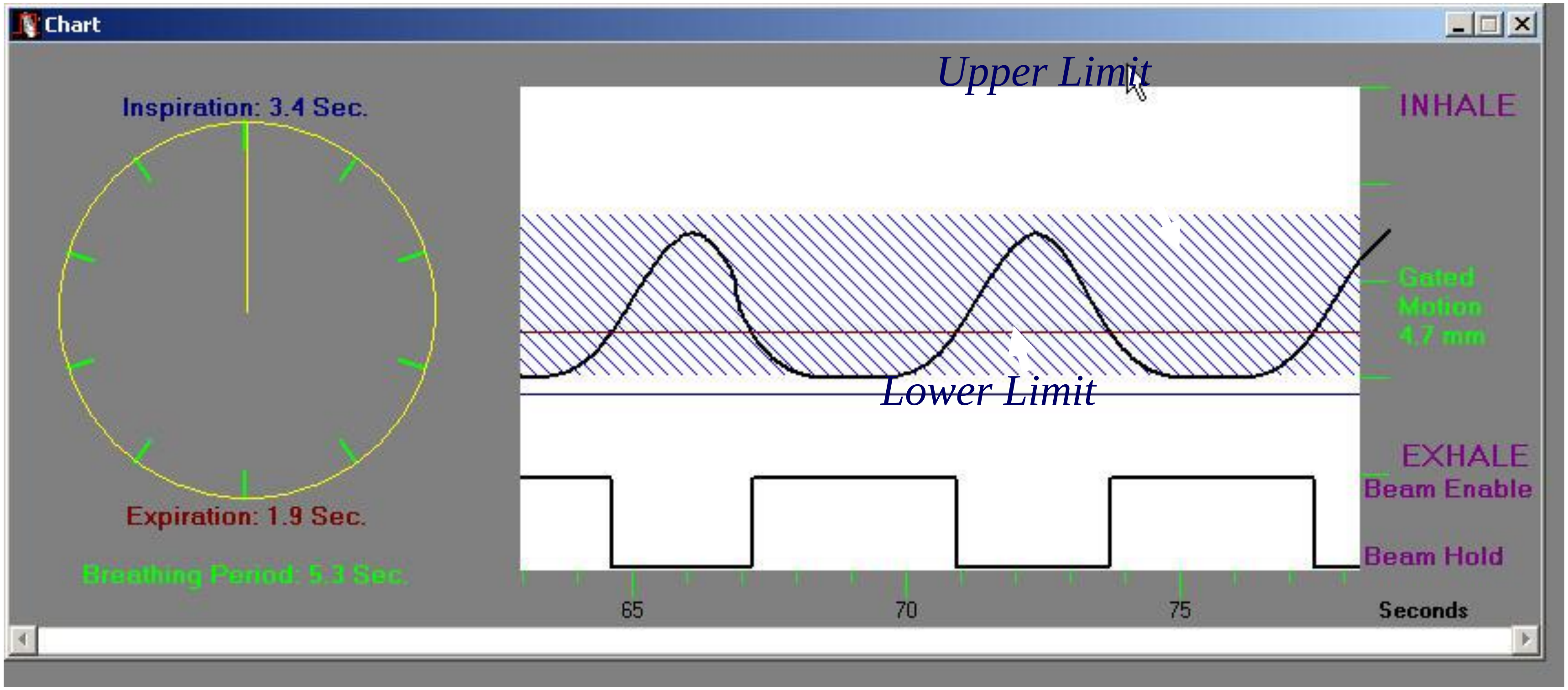
Internal Target Volume (ITV):

The range of the tumor motion is measured at the time of simulation and treatment ports can be designed to include this range of motion

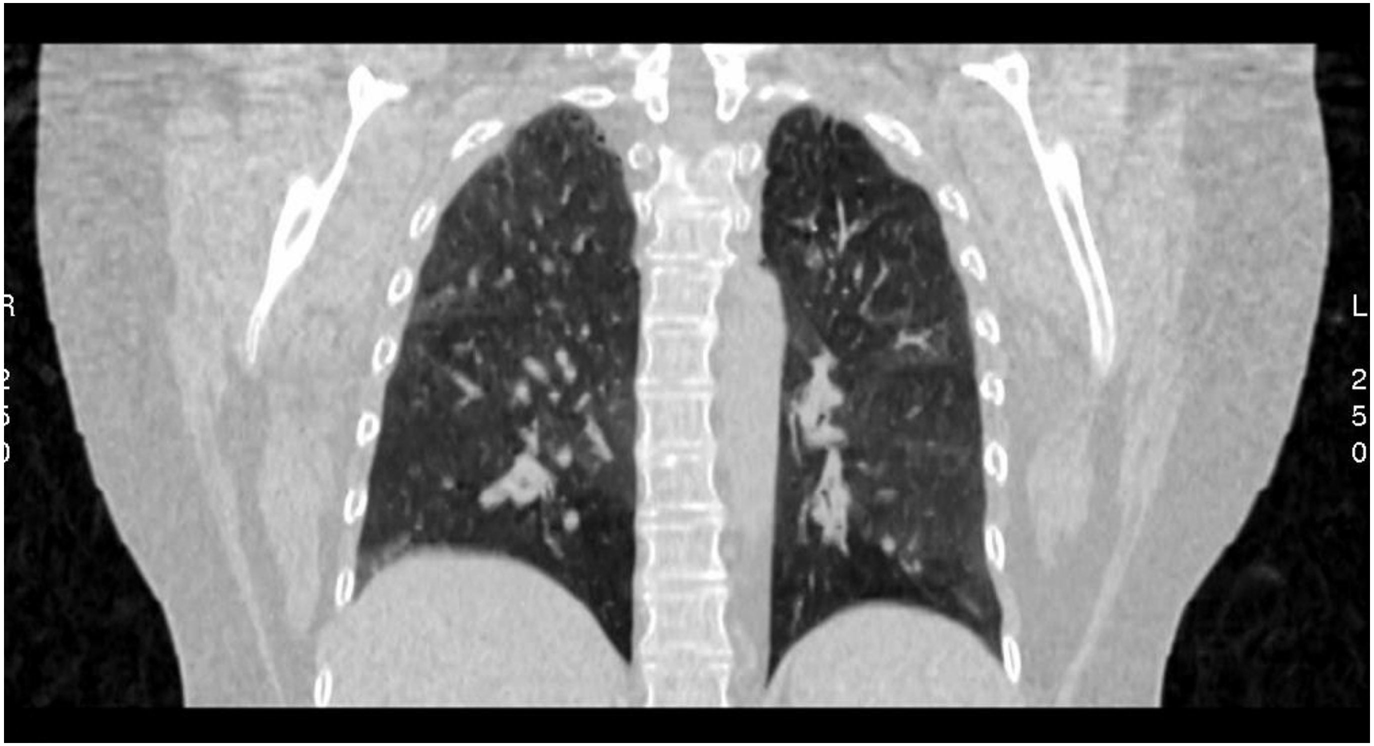
MV CINE

Dynamic Gating

Only turn the treatment beam on when the marker is within a given amplitude or phase range, this should only be done with gated imaging.



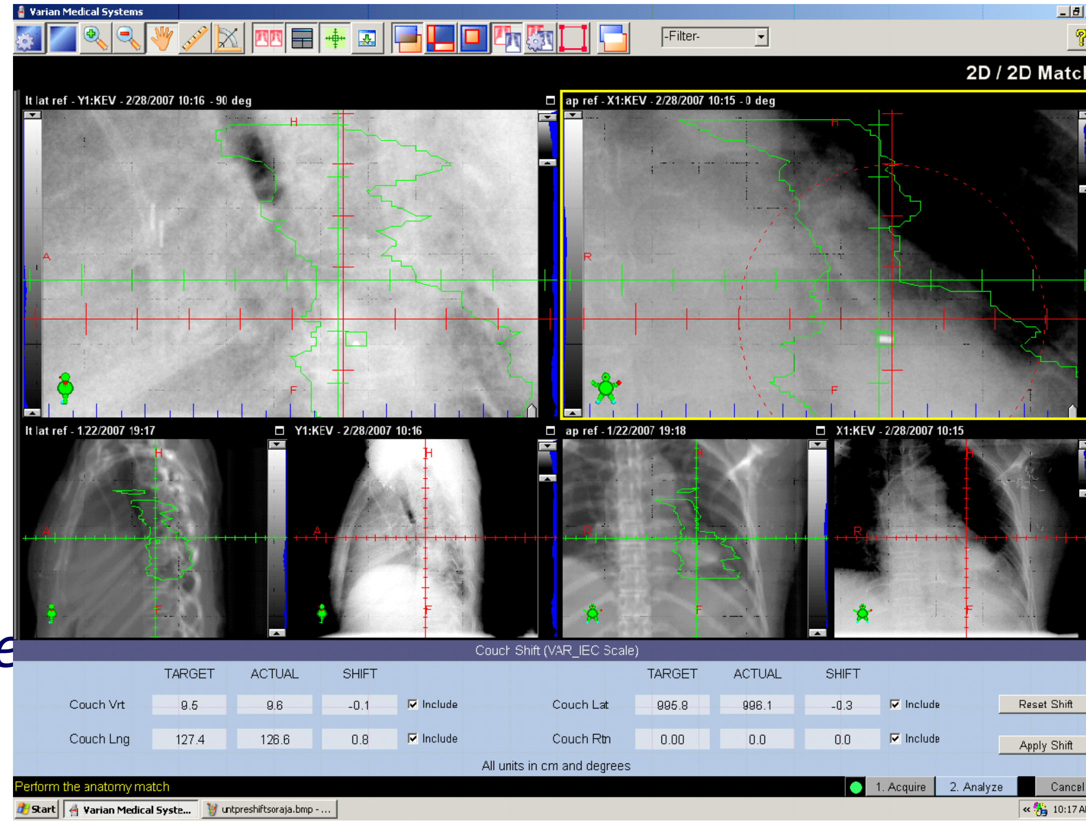
Gating still leave some residual motion in the gate
There is a trade-off between gate size and duty cycle on the linac.



These images represent a 30% duty cycle and expiration, there is still residual motion

Gate – but verify

- *Gating should only be done if the level of the gate can be verified each day*
- *At least one vendor will allow the imaging system to be gated by the same system that gates the treatment beam*
- *This will probably require the use of implanted fiducials for tumors not attached to bone*



Feedback Guided Gated Breath-hold (FGBH)

- Provide the patient visual feedback of their location in their breathing cycle.
- Set a very small gating window to minimize motion related margins.
- Ask the patient to voluntarily hold their breath within the gate
- Simulate over a number of breath-holds to access tumor position reproducibility
- Only turn on the beam when the patient is holding their breath in the gate.
- CBCT or CT-on-rails can be done during a series of FGBHs

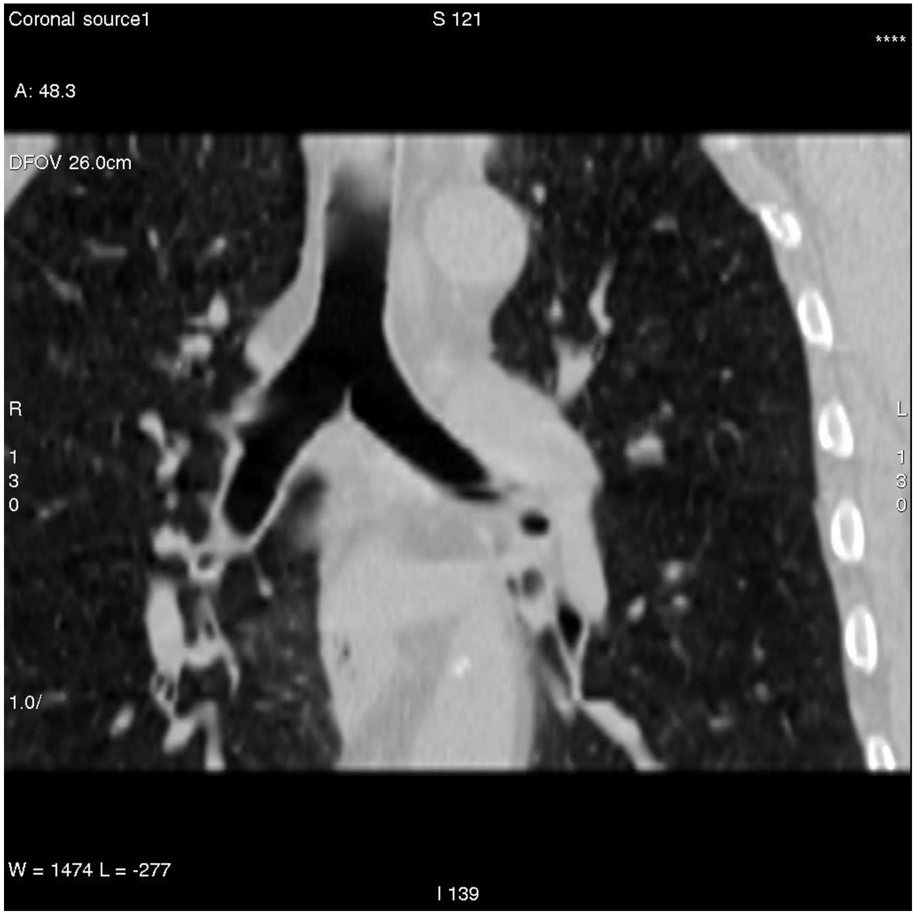
Breath-hold works best with patient feedback

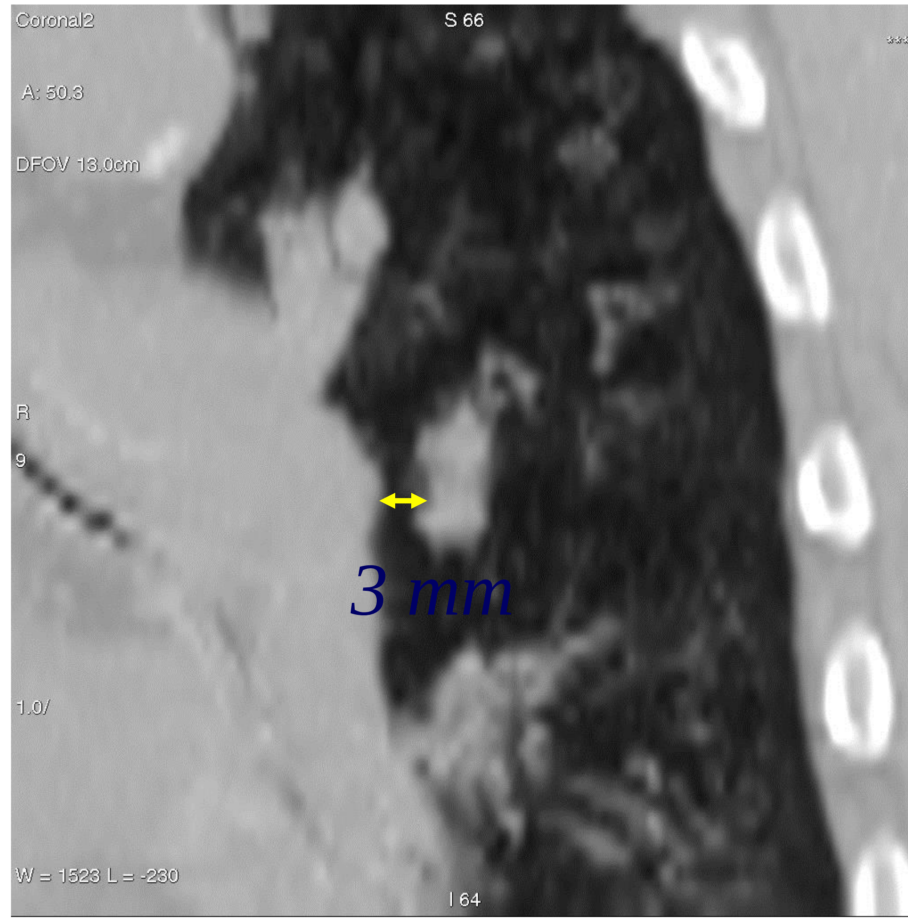
VR goggles feed part of the RPM screen through a scan converter

A Case Study In Respiratory Management

- Both GTVs and organs-at-risk (OARs) have motion ITV, IOARV associated with them.
- This is an SRS patient with 1 cm of separation between the GTV and OAR but only 3 mms between the ITV and IOARV.
- We tried
  - Abdominal Compression
  - Breath-hold at inspiration

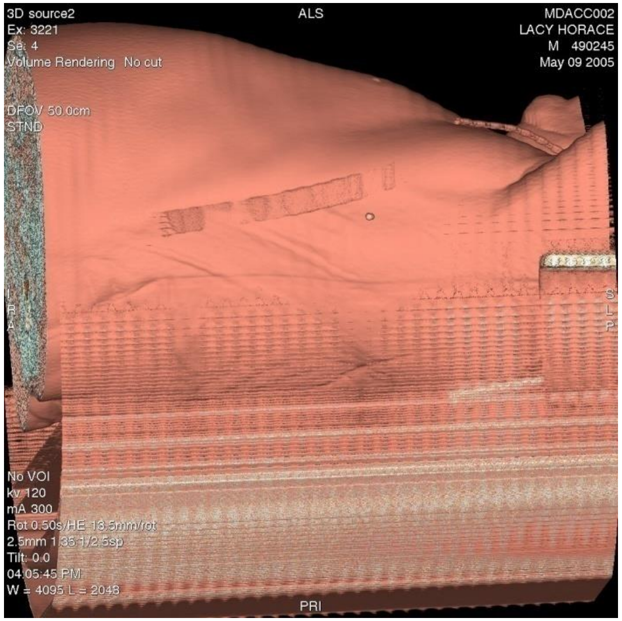
The problem

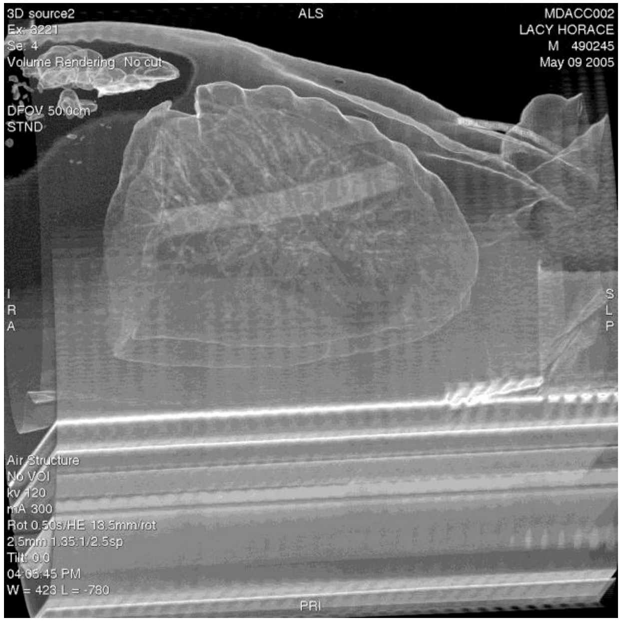

Coronal source1
S 121
A: 48.3
DFOV 26.0cm
R
L
1.0/
W = 1474 L = -277
I 139


Coronal2
S 66
A: 50.3
DFOV 13.0cm
R
L
1.0/
3 mm
W = 1523 L = -230
I 64

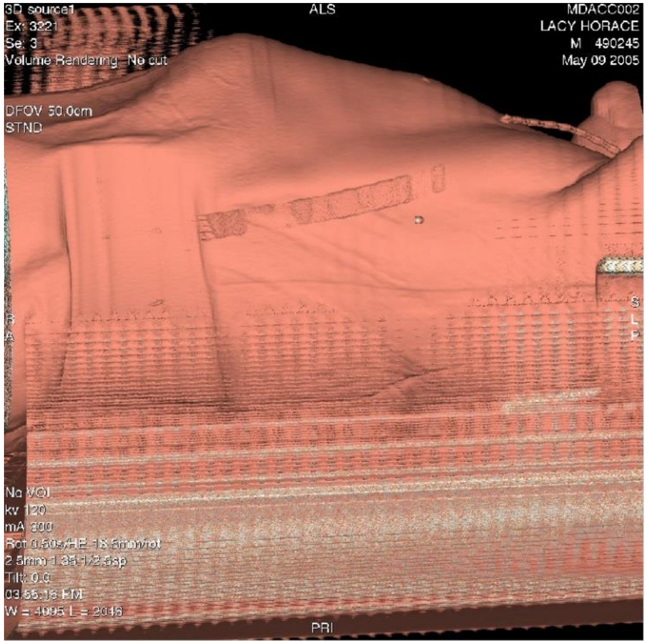
BH vs Abdominal Compression

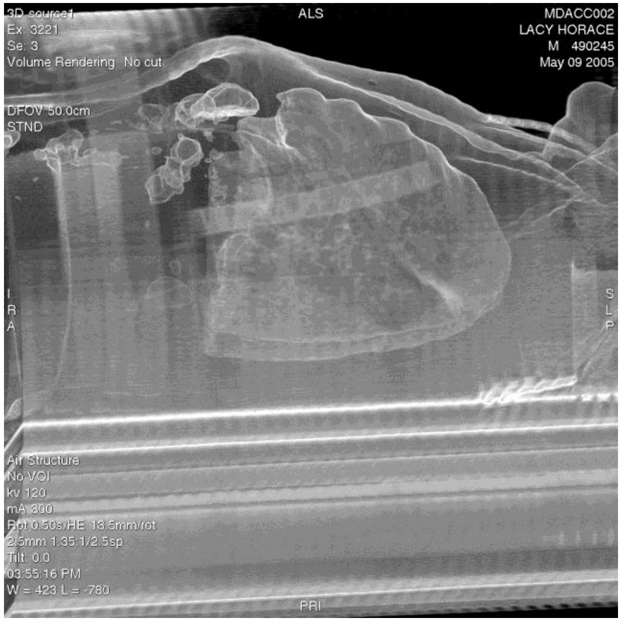
Breath-hold at inspiration



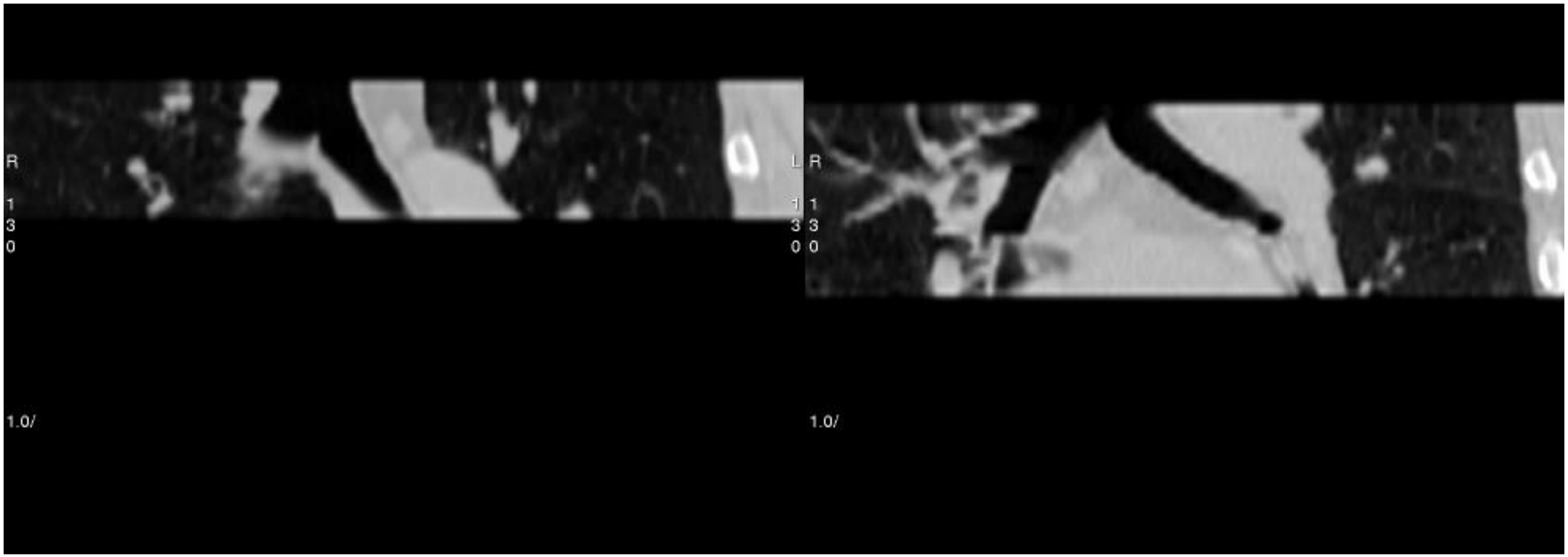


Abdominal Compression (expiration)





Both techniques work to reduce ITV

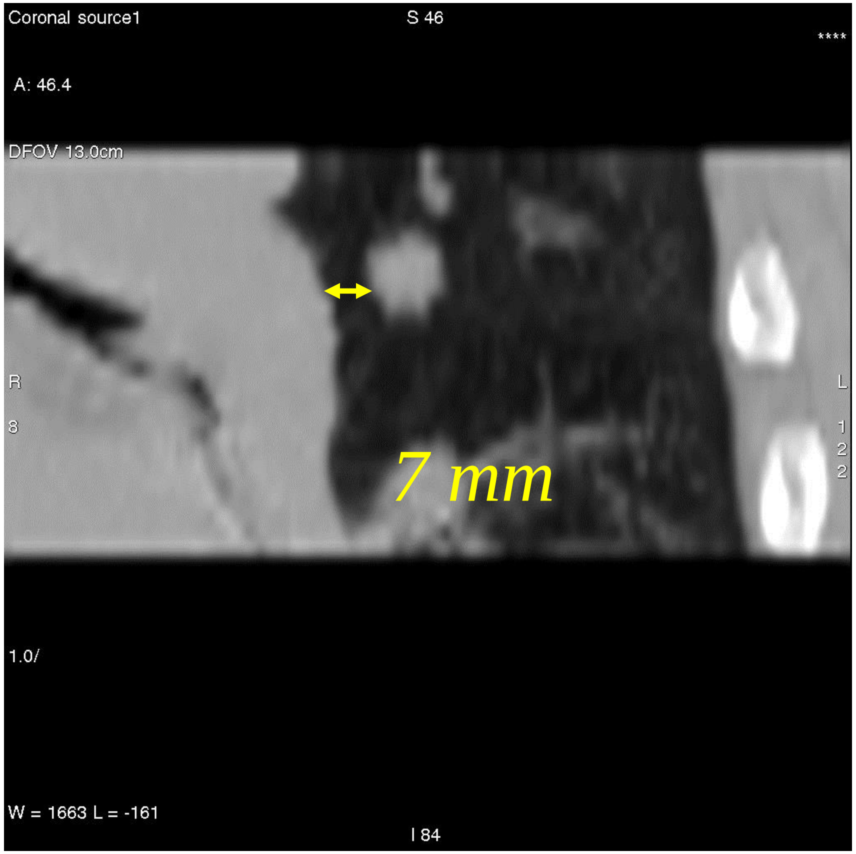


Repeat Breath-holds

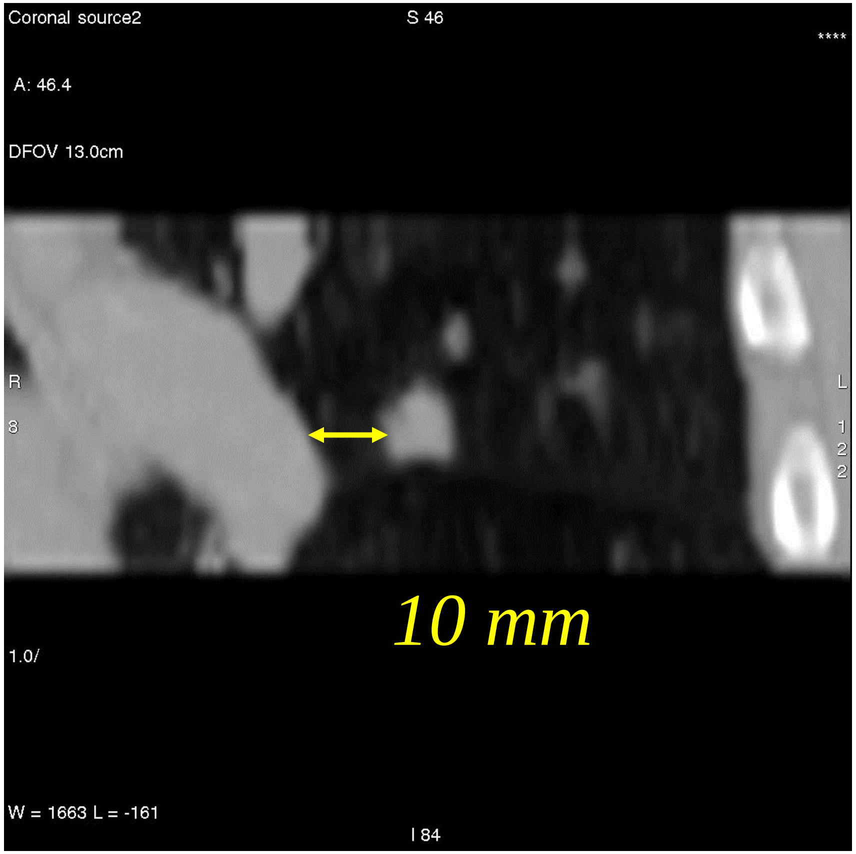
Abdominal Compression

The expiration breath-hold provides 3 mm more distance between the ITV and the OAR

Abdominal Compression



Repeat Breath-holds



Immobilization

Elekta Stereotactic Body Frame

Immobilization

- The problems of immobilization and localization are often mixed.
- This was necessitated by the lack of in-room imaging
- The degree of immobilization is a function of
  - Length of treatment
  - Patient compliance
  - PTV margins
  - PRV margins

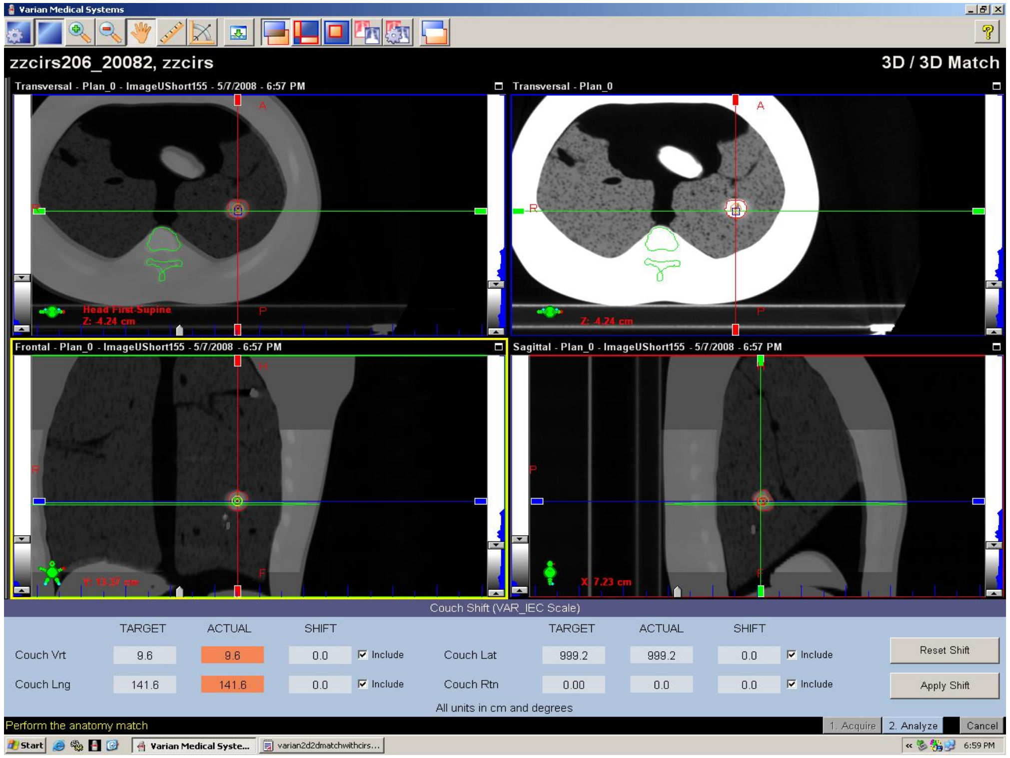
Immobilization

Stereotactic immobilization, not intended for localization, does a good job of immobilization.

Conventional immobilization, marking on skin. Not particularly good for localization or immobilization.

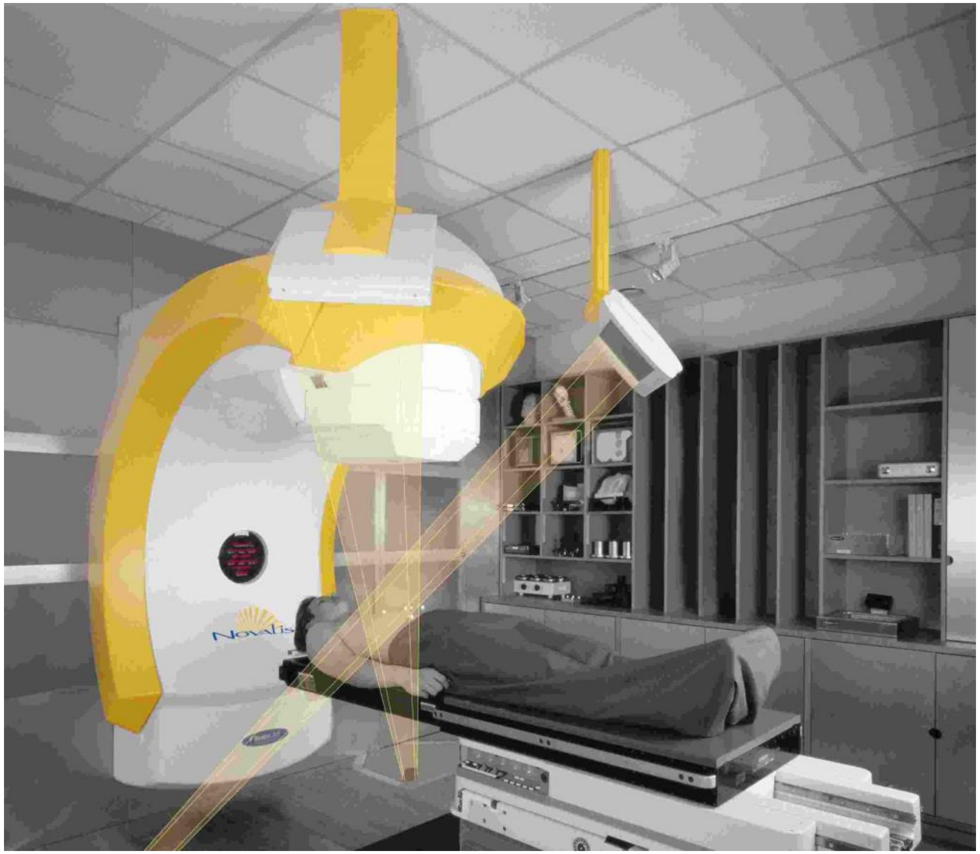
Methods of in-room setup

- Body frame
- Projection imaging
  - With fiducials
  - With gating
- Volumetric imaging
  - CT-on-rail
  - CBCT



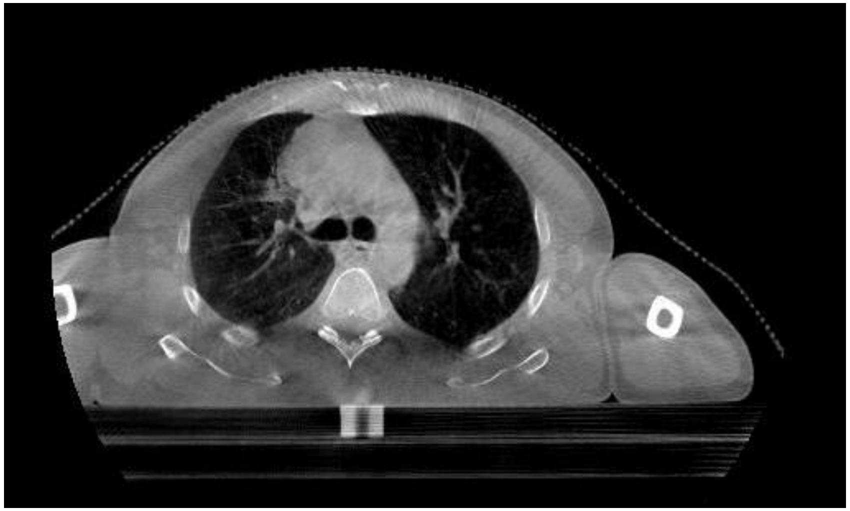
Projection Imaging

- Can be MV or kVp
- Can be gated with the same system as gates the treatment beam
- Can often not directly visualize the treatment site
- There are commercial systems that offer either real-time or near time orthogonal imaging



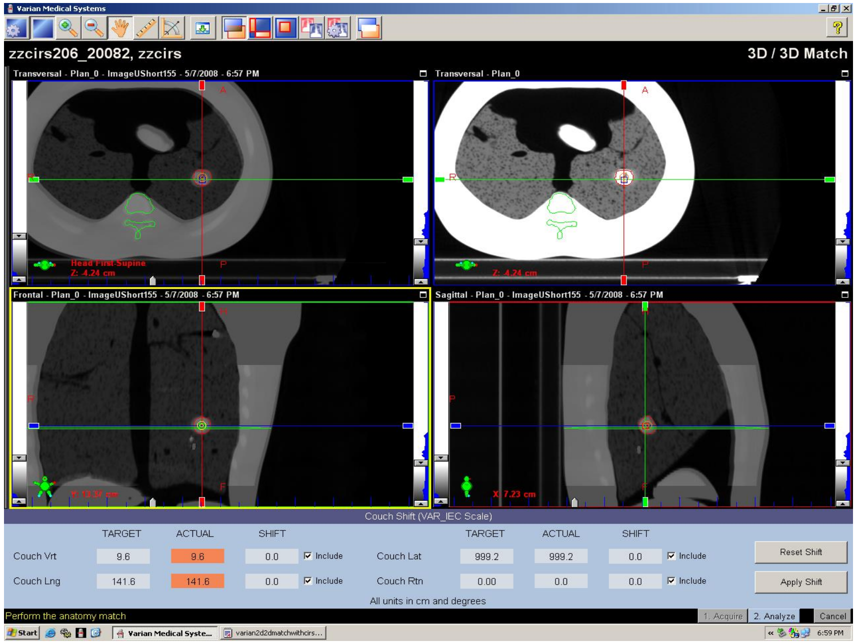
In-room Volumetric Imaging

- *X-ray tube and flat panel imager are mounted on the linac gantry*
- *In one rotation around the patient (1 min) 400 projection images can be acquired*
- *These can be reconstructed into a 13 cm long CT volume*
- *Cannot be gated but can be acquired under breath hold*

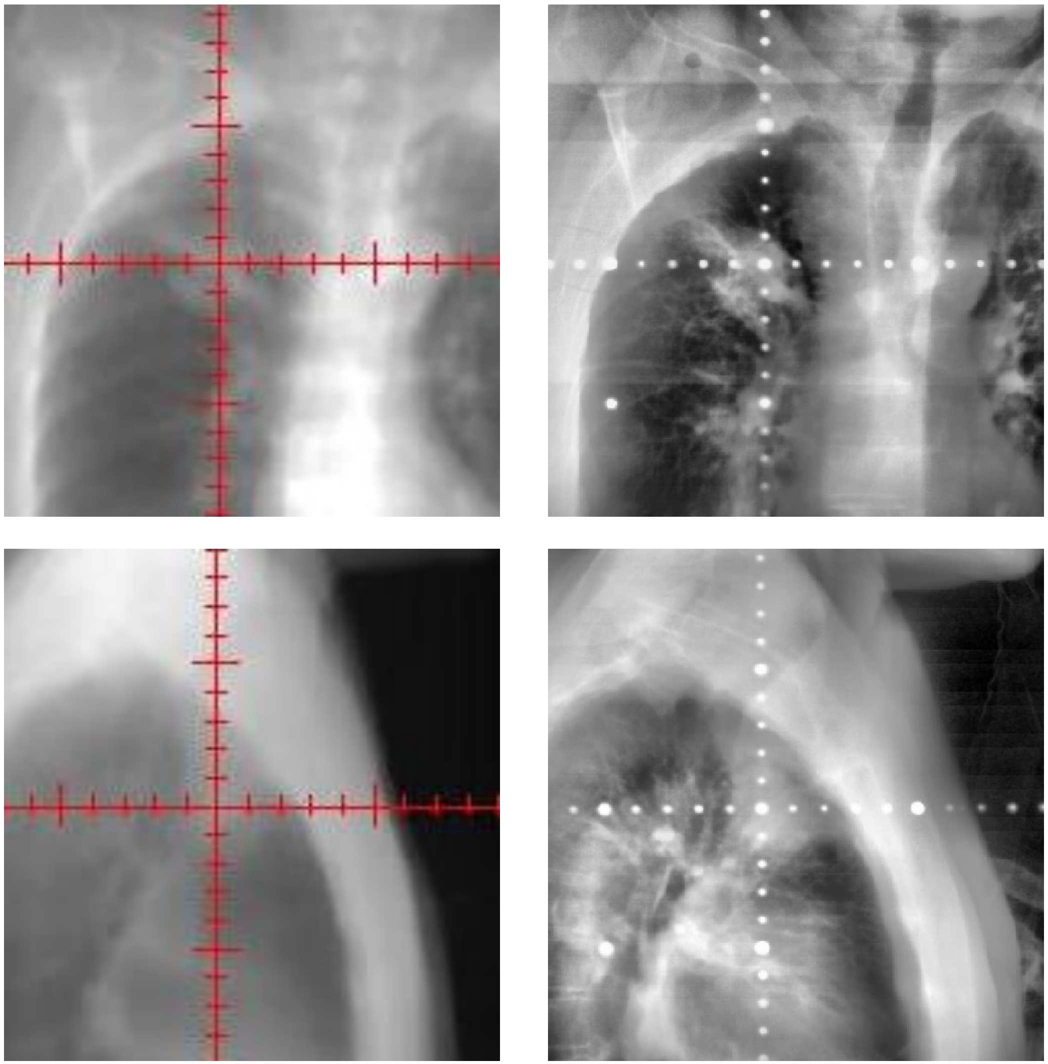


3D-3D matching

- Requires software
  - Manufactures have software embedded in the treatment consoles for CBCT
- Requires choices
  - Setup structures – tumor vs bone vs fiducials
  - Prioritization of TCP or NTCP
    - Case-by-case dependent



Validation of setup

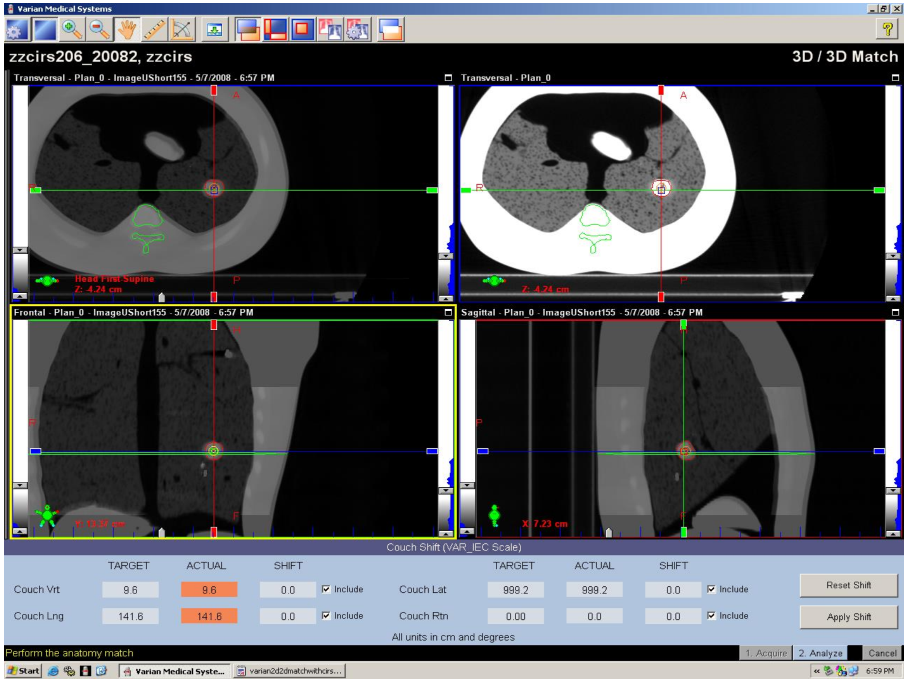


AP and lateral EPID images are visually compared to reference DRR's from TPS

NO SHIFTS ARE MADE BASED ON THESE IMAGES

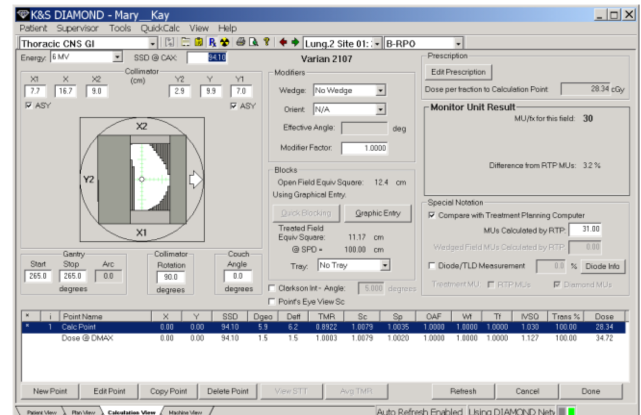
Problems discovered with final validation

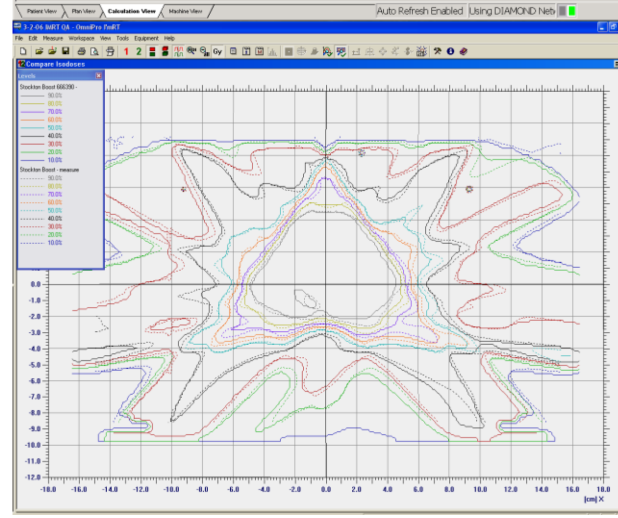
- Patient movement after 3D imaging
- Incorrect setup of 3D matching software
- Missed lateral shift by RTT



Pre-treatment patient specific QA

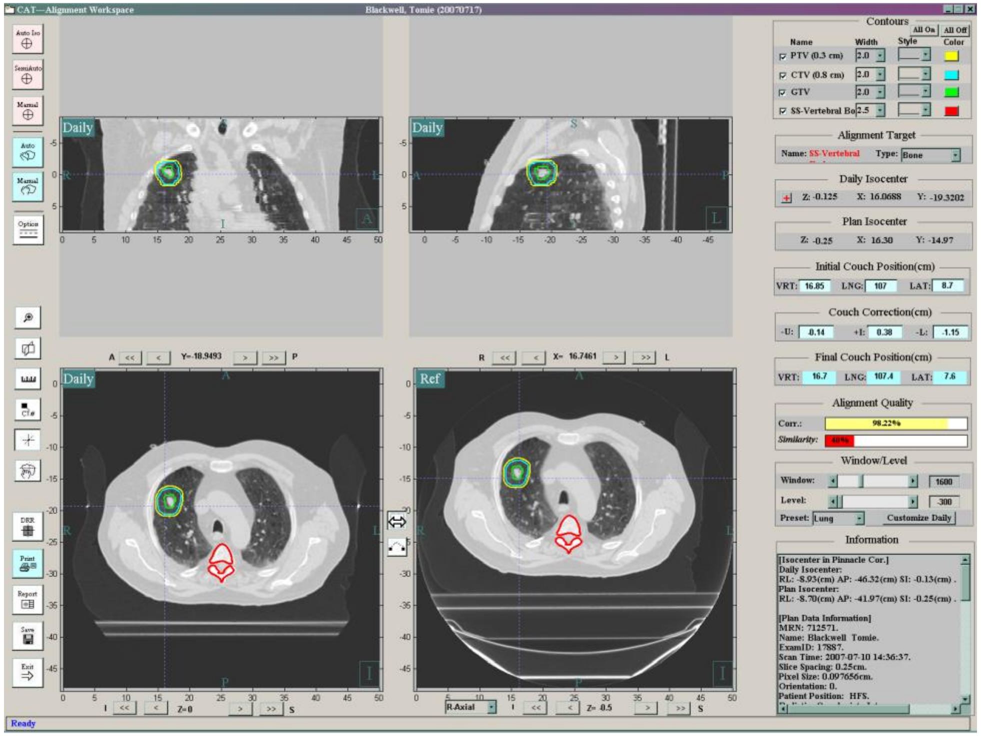
- For 3DCRT patient's
  - Verification of TPS calculations with an independent calculation system
    - Can be a challenge for small tumors in the lung due to loss of electronic equilibrium
- For IMRT patient's
  - Measurement based IMRT QA done, reviewed and signed by physicist and attending before the first fraction



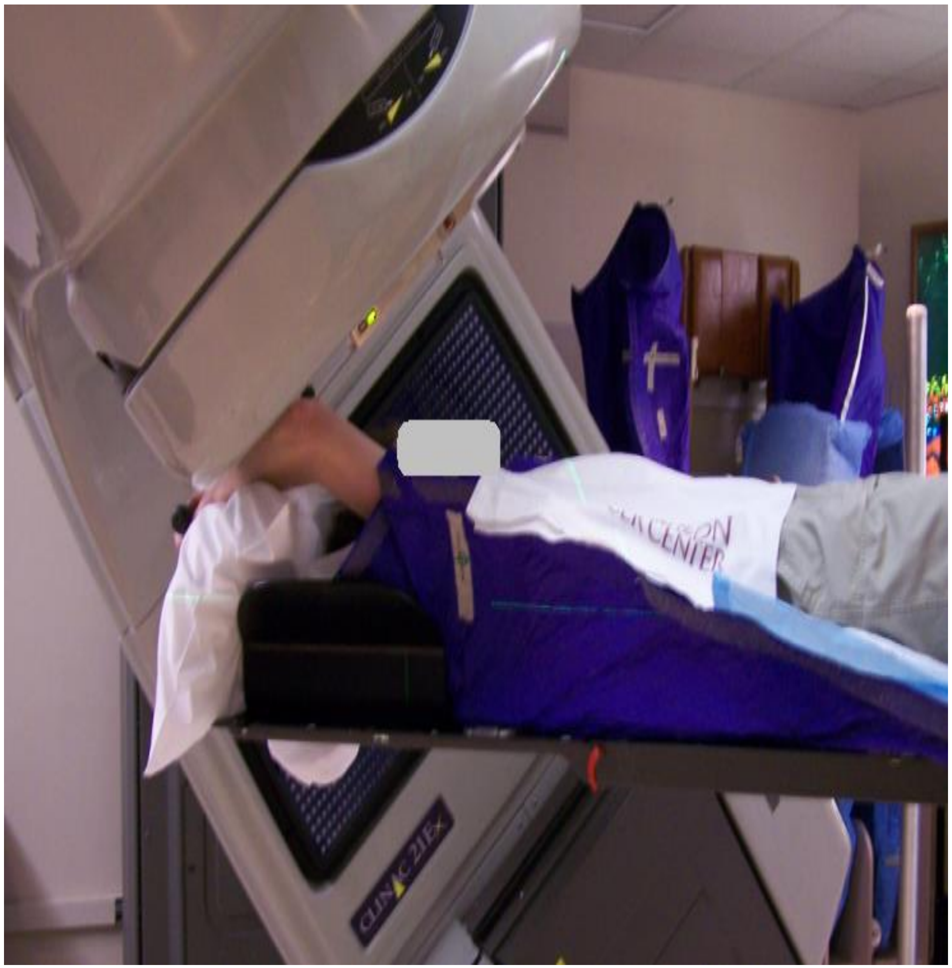


Pre treatment QA
Patient Set-up with CBCT

- The patient is aligned to the treatment target
- Changes in the patient's anatomy since simulation are evaluated to ensure the treatment goals are still meet
  - Patient rotation
  - Changes in breathing pattern
  - Changes in tumor or surrounding structures



Treatment



- Actual treatment 30 to 45 minutes depending on the number of beams and complexity of setup

Post treatment

- Post treatment evaluation (follow up clinic)
  - local failures
  - Skin changes
  - Lung changes
- Could the plan have been done better
- Do we need to change our dose constraints
- Do we need to change our margins

Final thoughts

- Hypo-fractionated radiation therapy
  - Can achieve superior local control
  - Is more convenient for the patient
  - Makes better use of the Linac
    - 45 min x 4 fx=3 hours(lung),
    - 90 min x 1 or x3 = 4.5 hours (spine)
    - vs: 15 min x 30 fx = 7.5 hours.

Final thoughts

- Hypo-fractionated radiation therapy
  - Has the potential to do real immediate harm to the patient
  - May result in more severe morbidity than traditional XRT
  - Has little room for error
  - Is more akin to surgery than XRT and the same degree of care is required

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