PHYSICS AND CLINICAL APPLICATION OF IMRT / IGRT , RADIOSURGEY AND SBRT

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- Intensity Modulated Radiation therapy (IMRT)
- Image Guided Radiotherapy (IGRT)
- Stereotactic Radio Surgery (SRS)
- Stereotactic Body Radiosurgery (SBRT)

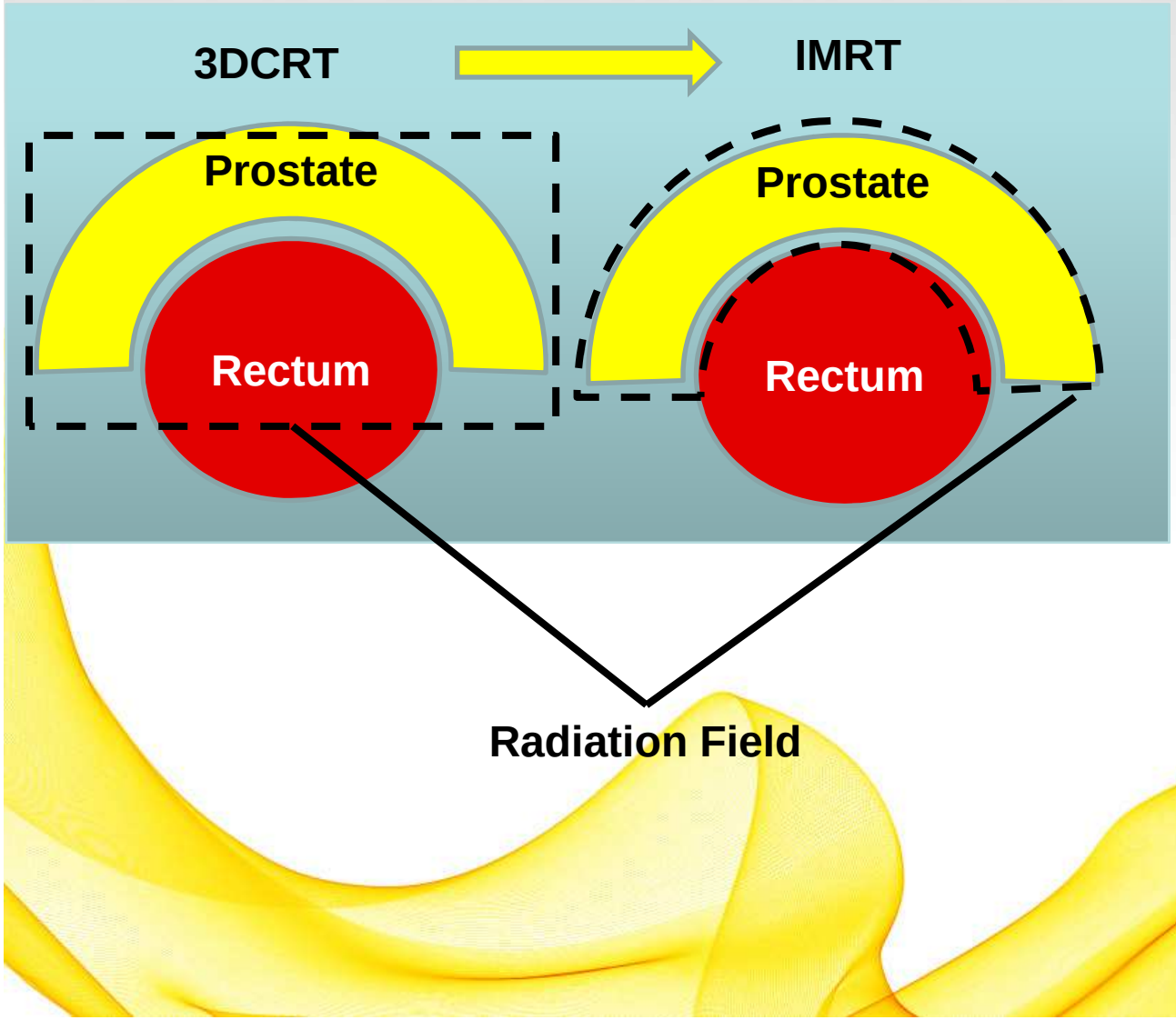
What is IMRT ?

- Intensity-modulated radiation therapy (IMRT) is an advanced form of three-dimensional conformal radiotherapy (3DCRT)
- The purpose of IMRT is to shape isodose lines by varying beam intensity in order to conform to clinical requirement

IMRT Advantages

- Conformality
  - Concave shaped dose distribution
- OAR sparing with sharp dose fall-off
- Dose escalation
- Lower rate of complication
  - Reduced cost of patient care
- SIB

The Magic Bullet "Conformality"



- Conformality
- OAR sparing with sharp dose fall-off
- Dose escalation

IMRT Methods

Type	Intensity modulation method
Segmental MLC (step and shoot)	During Beam On , MLC, Table & Collimator stationary. Each gantry angle multiple segments
Dynamic MLC (sliding window)	MLC move while beam on.
Intensity-modulated arc therapy (IMAT or VMAT or Rapid ARC)	MLC move while the gantry is rotating.
Serial tomotherapy	Gantry rotates around the patient with the couch fixed. Binary leaves modulate a fan beam. Upon completion of each rotation, the couch is moved in a step-wise fashion
Helical tomotherapy	Gantry and couch move synchronously. Binary leaves modulate a fan beam

REQUIREMENTS FOR IMRT

- Medical Linear Accelerator
- MLC
- Necessary software
- QA equipments

Terminology

- **DMLC**
  - IMRT delivery mode in which leaves continuously move and shape the beam intensity while the radiation is turned on.
- **SMLC**
  - IMRT delivery mode in which leaves only move when the radiation beam is turned off and remain in pre-defined position while the required radiation doses are being delivered.
- **Segment (control point)**
  - Shaped aperture formed by MLCs with uniform beam intensity;

- **Score**
  - Numeric value of the objective function that represents a figure of merit indicating the quality of a treatment plan.
- **Forward planning**
  - Trial and error method where the treatment fields or beam weights are modified iteratively to achieve acceptable clinical solution.
- **Inverse planning**
  - Optimization process that translates mathematical formalism of clinical requirements into deliverable intensity patterns.
- **Class solution**
  - Use of clinical experience based on solving similar cases with the same treatment technique or the same approach.
- **Iterations**:
  - executing the same set of instructions a given number of times or until a specified result is obtained

Process of IMRT

6 steps

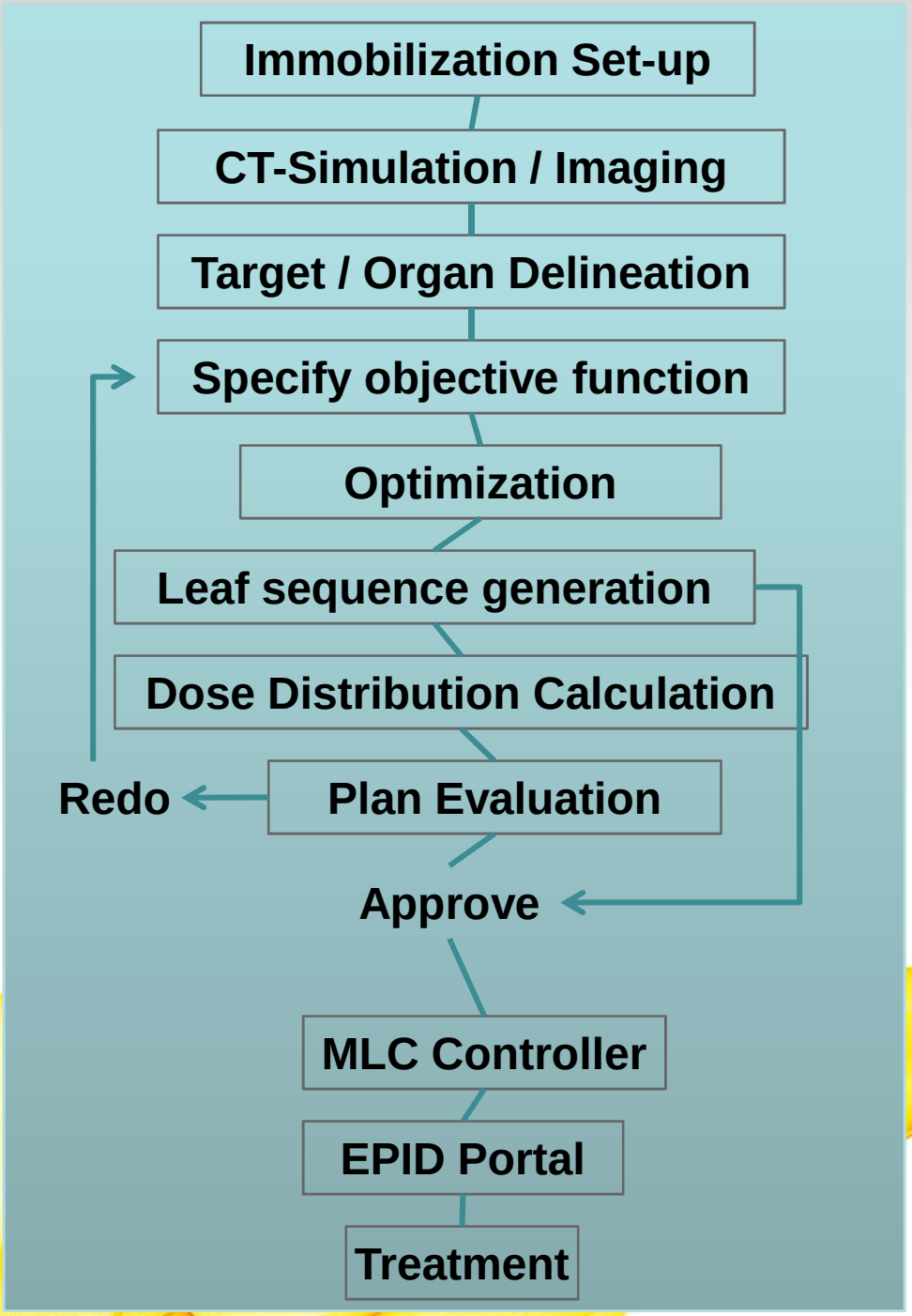
- Immobilization
- Simulation
- Target delineation
- Treatment planning and optimization
- Quality assurance
- Treatment delivery

Physics Components of IMRT

ASTRO recommendations for Patient selection

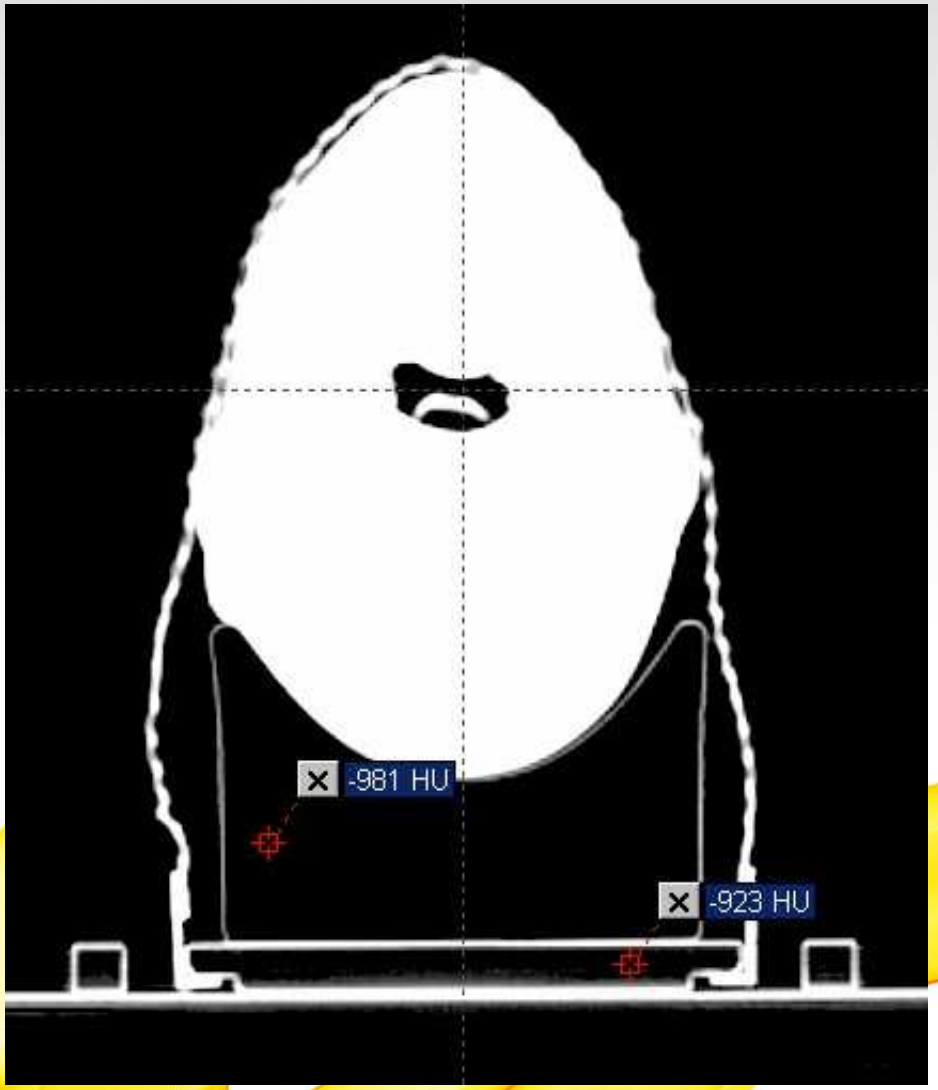
- Situations requiring IMRT
  - Irregular target
  - Close proximity to critical structure
  - IMRT only option to cover volume with narrow margin to protect adjacent structures
  - Nearby previously irradiated area
  - Conformal dose distribution required for concave treatment target

The IMRT Process



Immobilization accessories

- Air equivalent (low density)
- Neck rest and base plate



Delineation of target

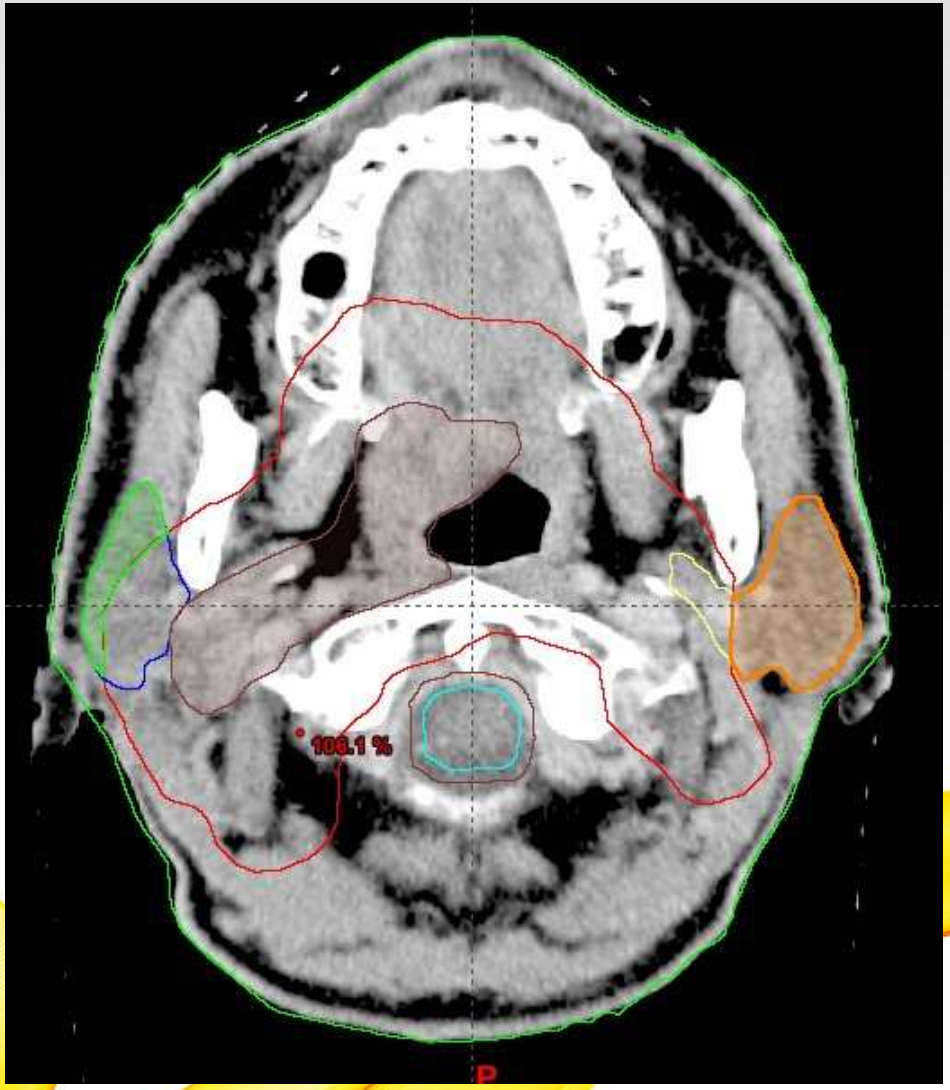
- Use of clinical information and multiple imaging modalities
- GTV, CTV and PTV

Delineation of OARs

- OARs : parallel and series
- Parallel: parotids, ears, TMJs, duodenum, liver, GI
- Series: spinal cod, brainstem, optic chiasm, nerves, lens, brain, eyes, mandible, temporal lobes
- For serial organs, Planning organ at risk volume(PRV) should be delineated

Planning risk volumes (PRV)

- PRV
- spinal cord/brain stem
- Uninvolved parotid glands

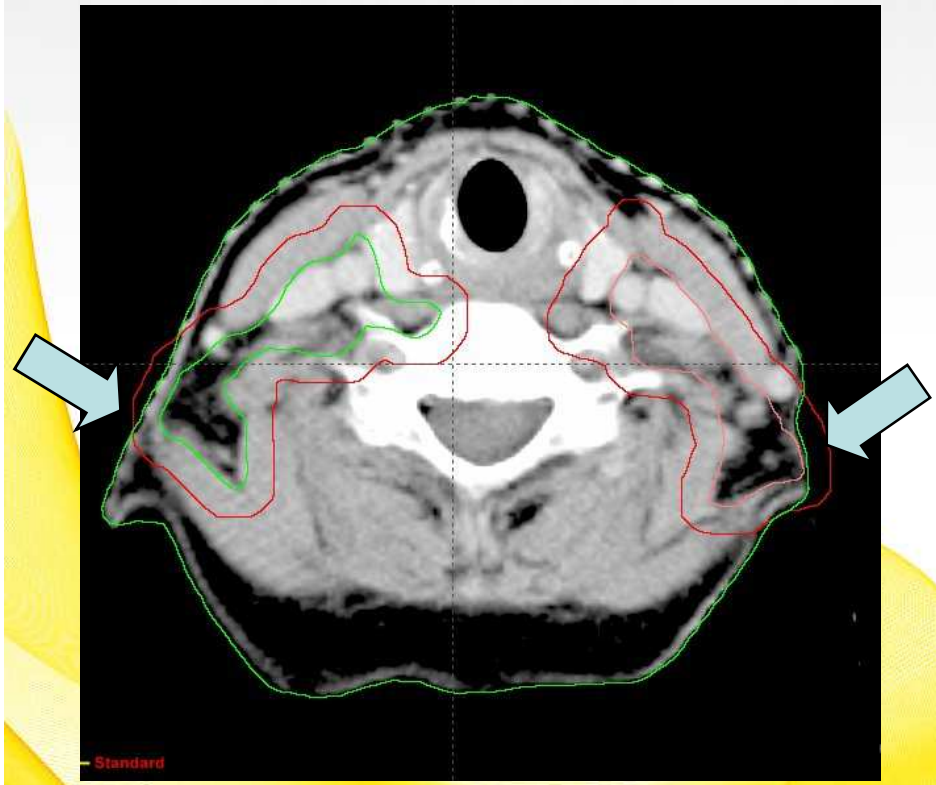


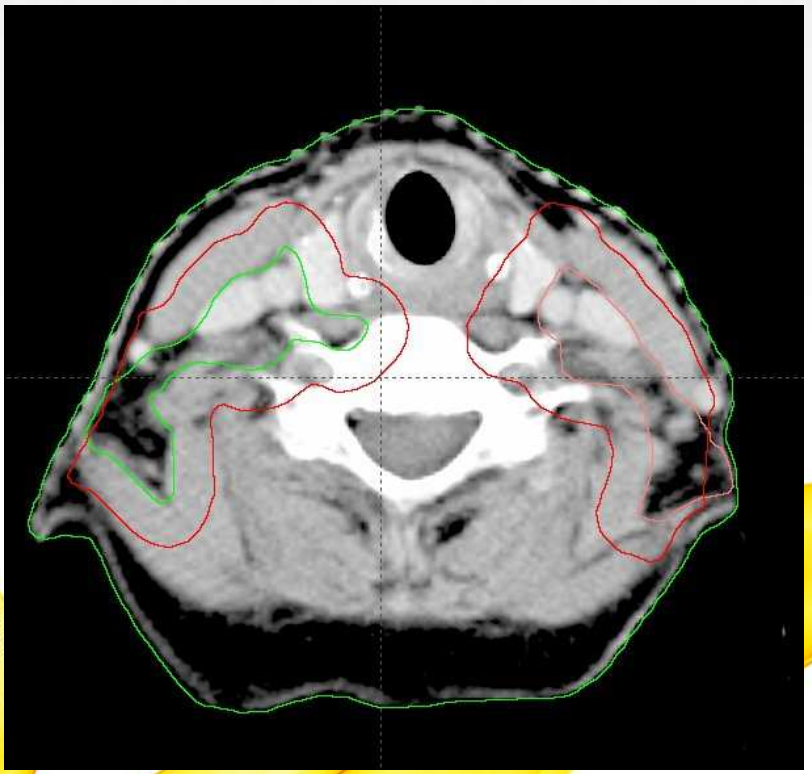
Remaining volume at risk

- Structures not included in CTV or OARs should be delineated as remaining volume at risk (RVR)
- Dose constraints to RVR avoids unsuspected high dose regions
- Is useful to estimate the late effects of irradiation specially carcinogenesis

Buildup region

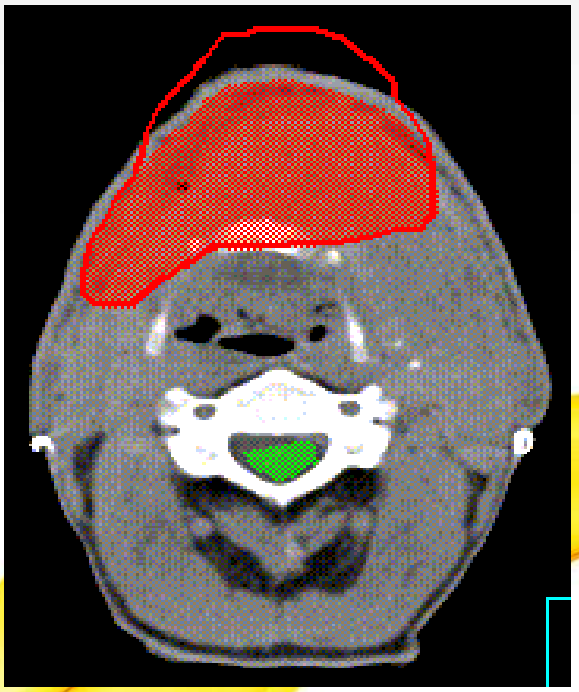
- Important when target regions (PTV) extend into the buildup region.
- Calculated doses are often inaccurate and lower than delivered doses.





Buildup region

Likely to cause hot spots in the target and elsewhere as a result of inverse planning engine fighting with the buildup effect – may cause excessive skin reactions and compromise the plan quality.



Treatment planning & optimization

Planning

Forward Planning

from field definition to dose distribution

T/t parameters

↓

Dose calculation

↓

Dose distribution

↓

Dose delivery with uniform radiation intensity

Inverse Planning

from dose distribution to field definition

Dose delivery with non-uniform radiation intensity

↑

Leaf sequence generation

↑

Optimization

↑

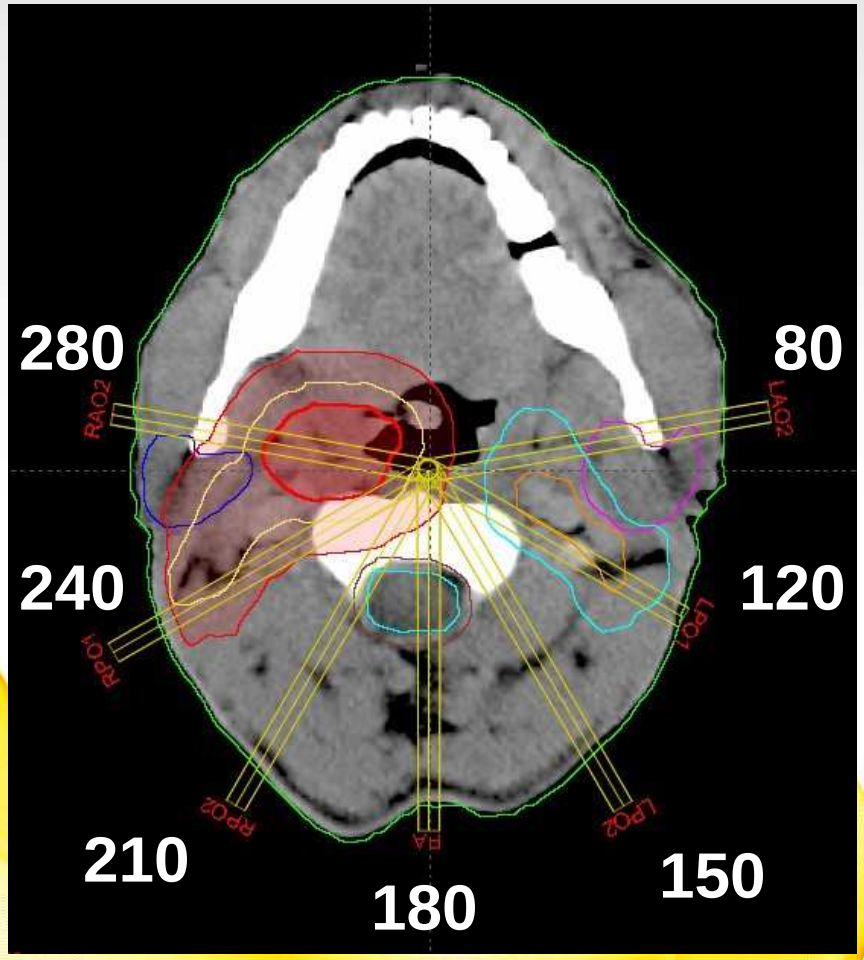
T/t goals (Objective Function)

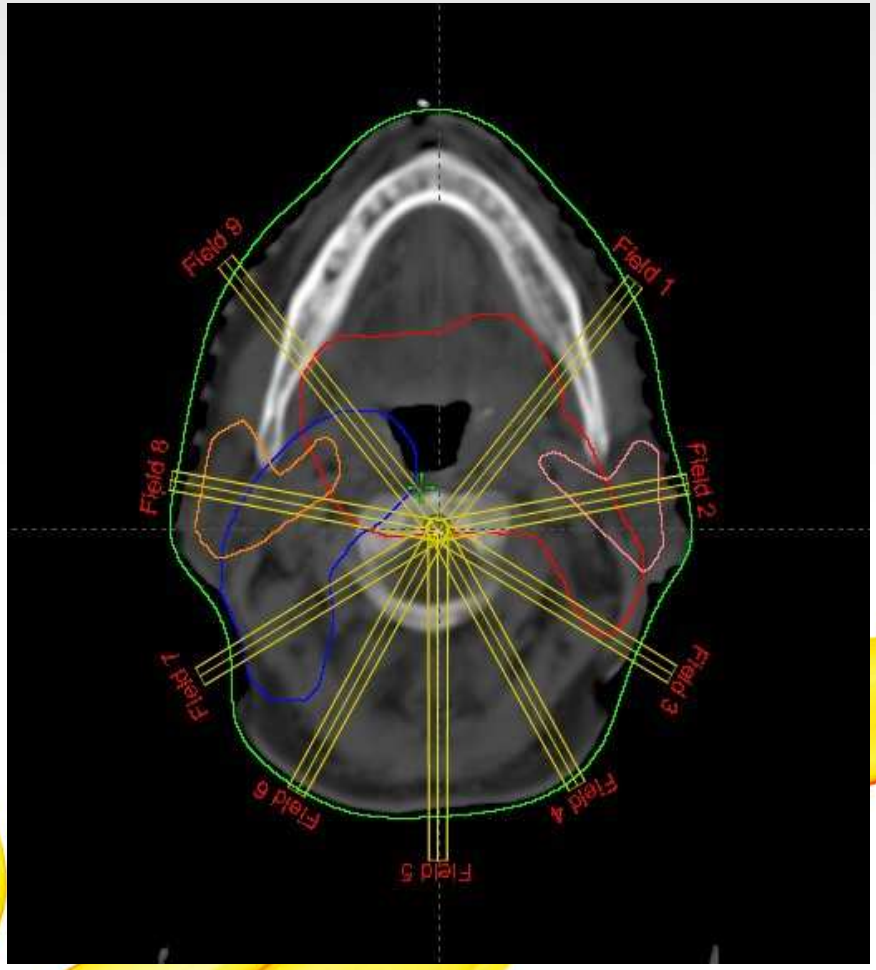
Beam selection

- Basic principles
  - Choosing the shortest pathway to irradiate the tumour
  - Avoiding direct irradiation to the critical structures
  - Keeping a large beam separation as possible
  - Two parallel opposed beams not used they provide less beam variables for optimization

Beam Placement

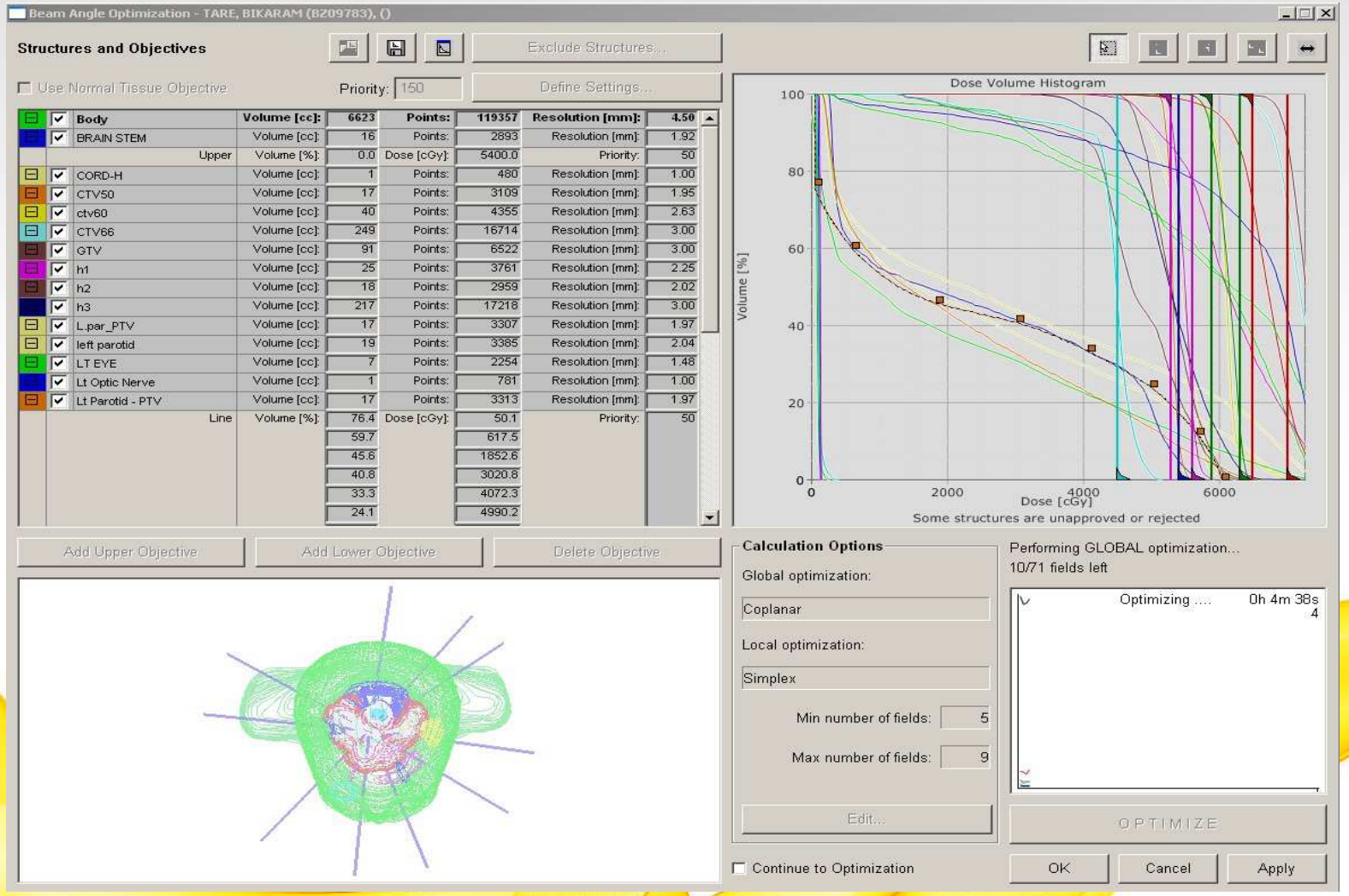
- Depends on target shape and location





Beam Angle Optimization

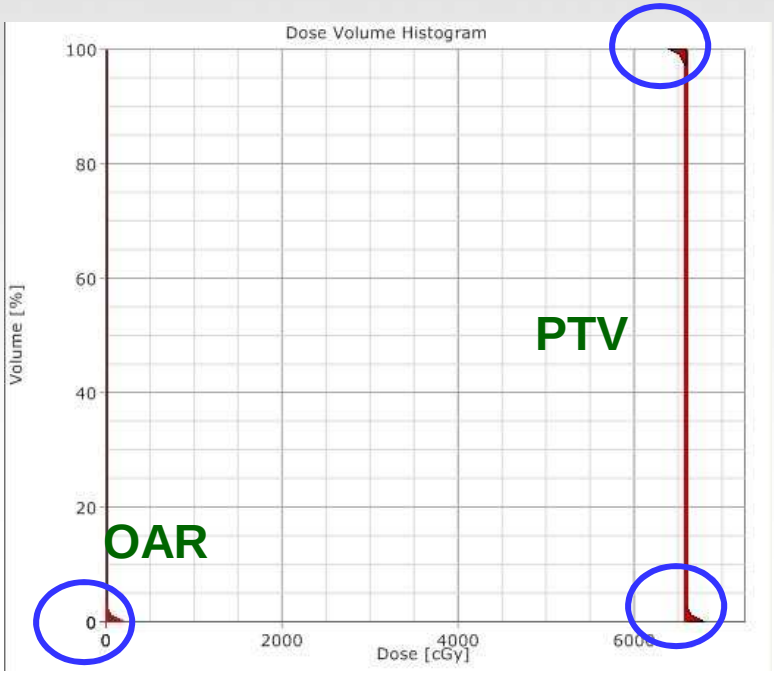
- Optimum beam angles can be derived by using beam angle optimization available with TPS



Planning Objectives (Constraints)

Ideal objectives

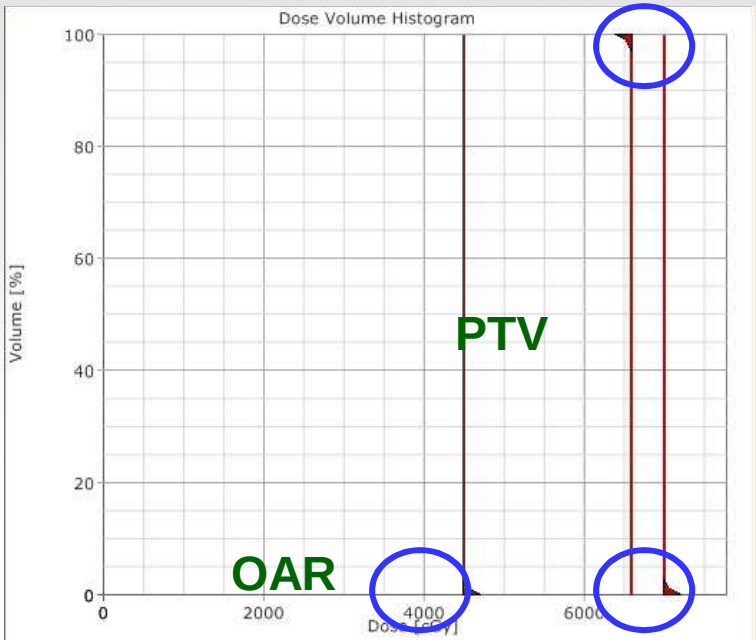
- PTV
  - Lower objective:
  - 100% volume = 100% prescription dose
- Upper objective:
  - None of PTV volume receive more than 100% dose
- OAR
- None of the OAR volume receive any dose
- Non realistic:
  - Never practically achievable



Planning Objectives (Constraints)

Realistic objectives

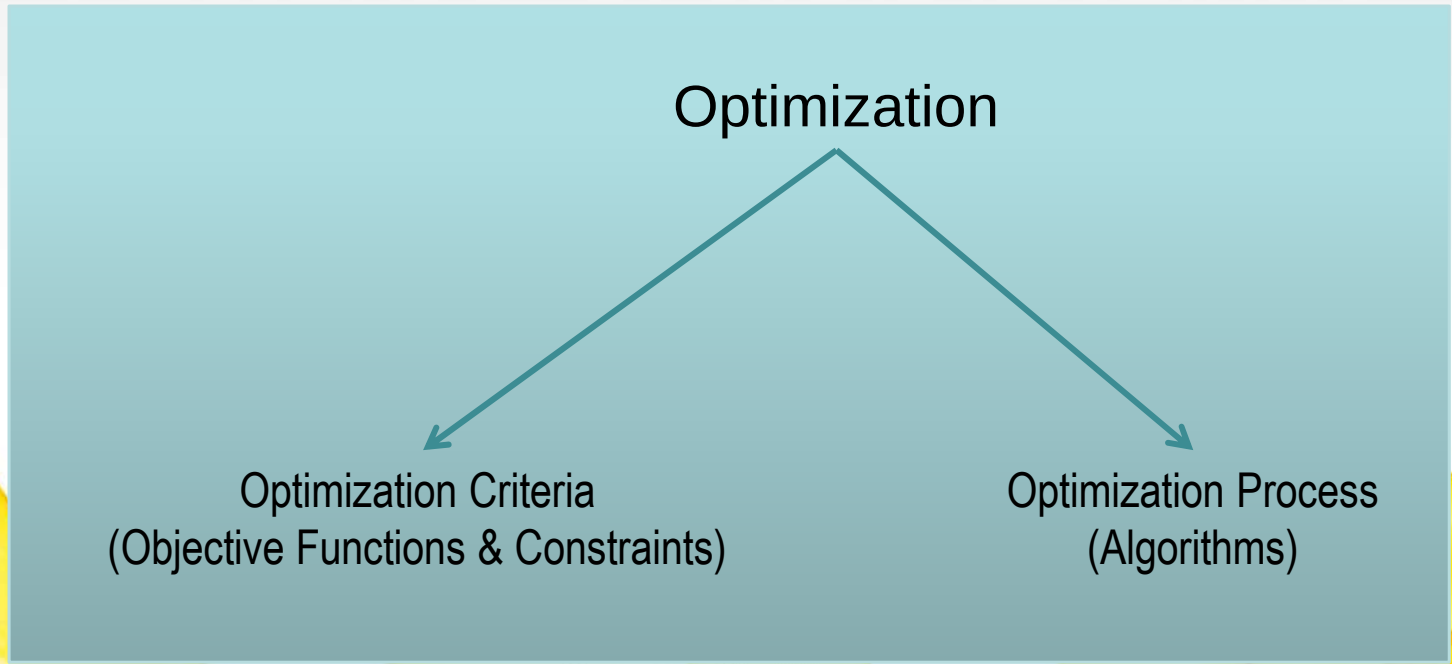
- PTV
- Lower objective
  - 100% volume = 95% prescription dose
- Upper objective
  - None of PTV volume receive more then 108% of prescription dose
- OAR (serial organs)
- None of the OAR volume receive more then tolerance dose



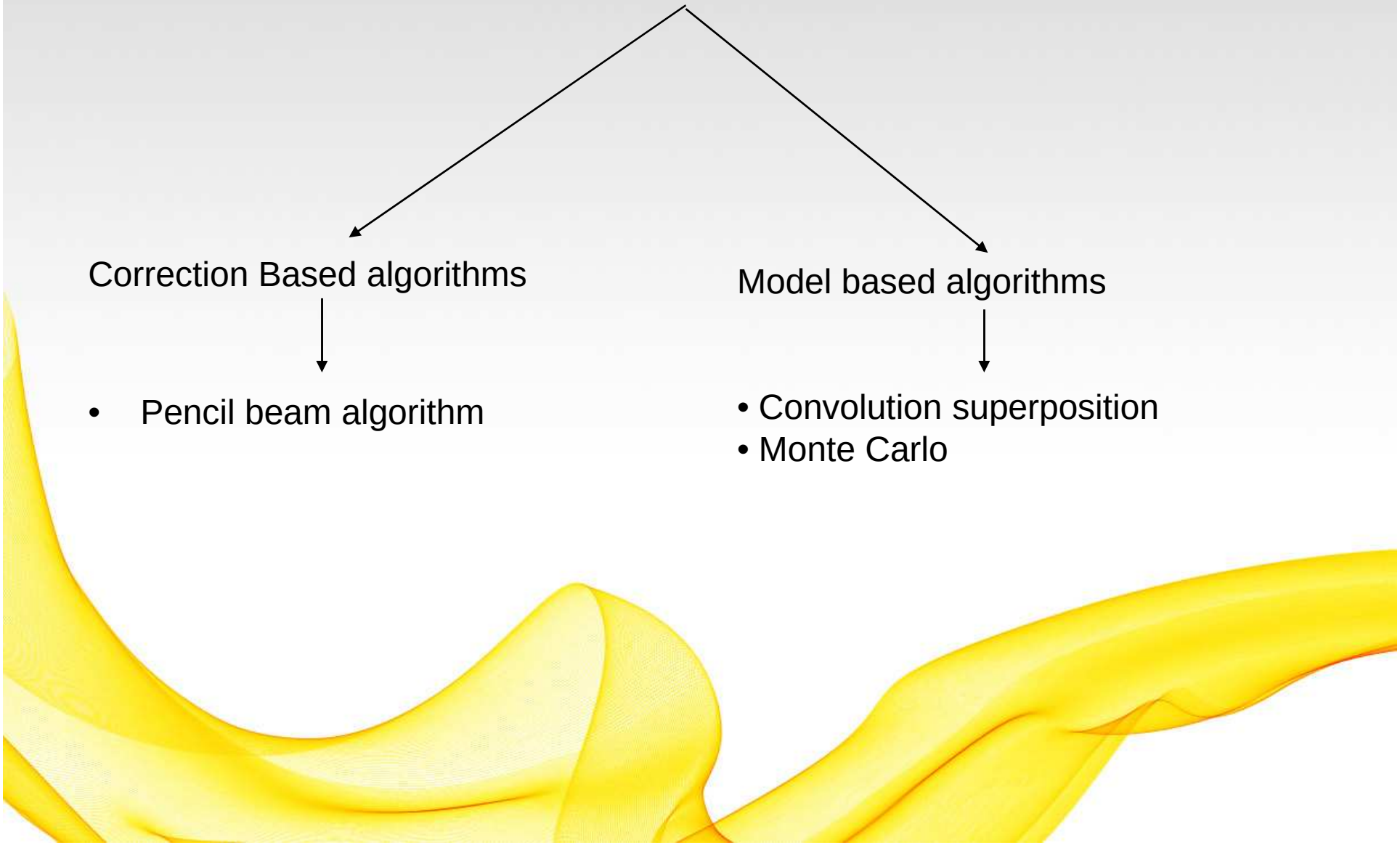
Optimization

Definition:

Systematic computerized process to generate a large number of plans rapidly and to evaluate and rank them according to some specified criteria



Dose calculation algorithms



Pencil beam algorithm

- Correction based model depend on empirically measured data for a limited number of situations.

- Correct the dose distribution for the presence of the beam modifiers, contour corrections, tissue heterogeneities, scatter and other issues encountered in treatment planning of real patients.

Bourland , Chaney and Ostapiak

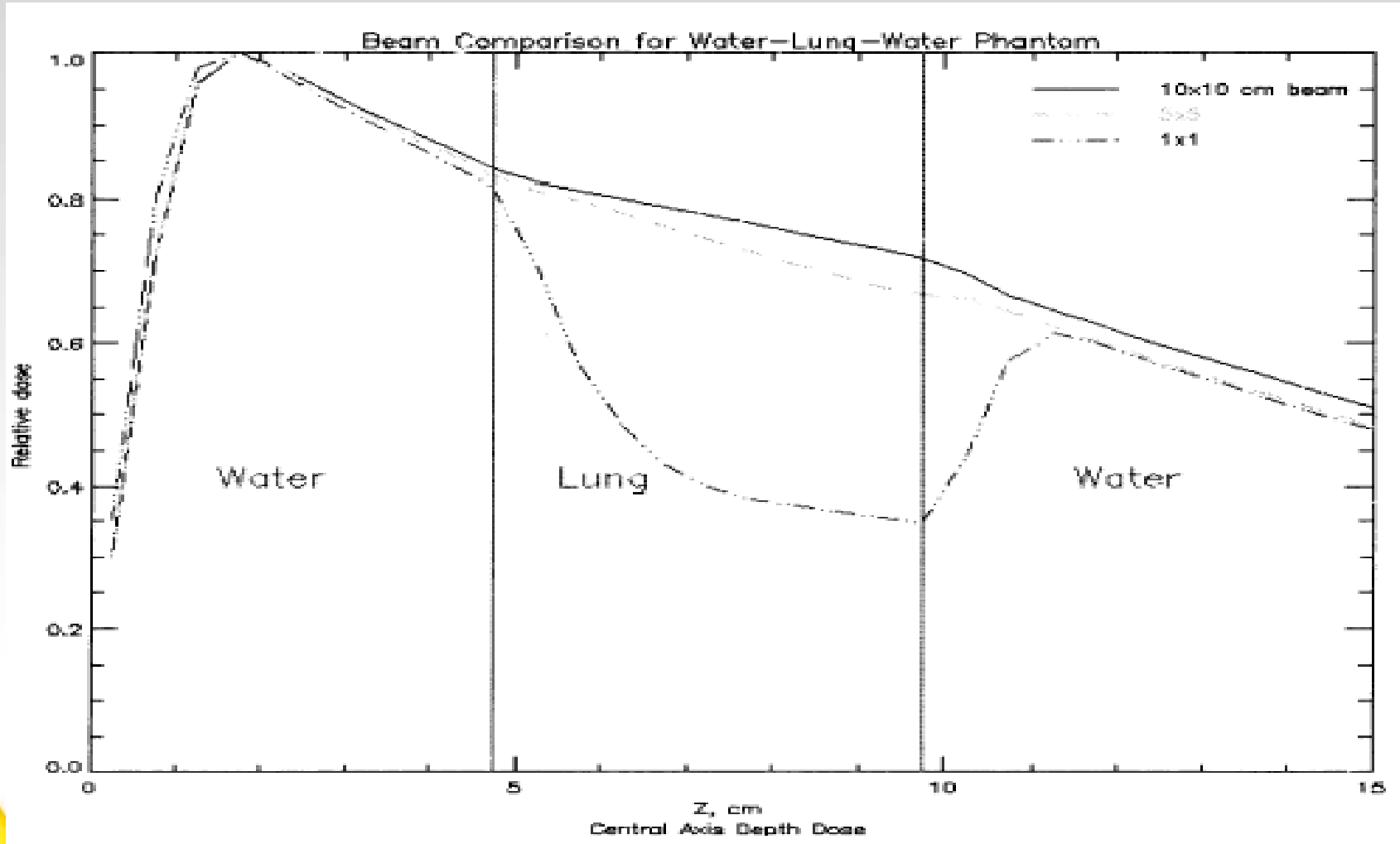
The dose at a point resulting from each individual beamlet is calculated using the product of

- constants
- MUs delivered
- Inverse square law
- Tissue-Maximum Ratio (TMR)
- Output factor
- Transmission factor
- Off-axis ratio

- Total dose at a point is summation of doses contributed by individual pencil beams

- This kind of simplicity offer significant speed advantages for use in the optimization code

- **But,** have limited accuracy particularly for 3D heterogeneity correction in lung and tissue interfaces especially when electronic equilibrium is not fully established**.**



Central axis 4 MV X-ray depth–dose curves computed for a variety of field sizes in a water phantom with a lung-equivalent slab (0.3 g/cm3)

Model based algorithms

- Compute dose distribution with a physical model which **simulates** the actual radiation transport.
- Simulation of transport of Primary photon, scattered photons and electrons separately.

  – Convolution-Superimposition

  – Monte-Carlo

Convolution superposition algorithms

- Based on the kernel-based models, which directly measure or compute the dose in a phantom or patient.
- Primary photon transport simulation as well as Kernel computation can be done using Monte Carlo code(EGS4)
- Takes into account beam energy, geometry, beam modifiers, patient contour, and electron density distribution

Radhemohan

Monte Carlo

- Monte Carlo is a **computer program** (MC code) that **simulates** the transport of millions of photons and particles through the matter.

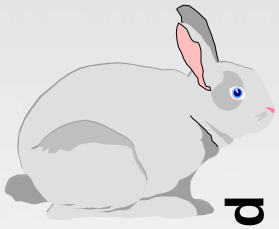
- It uses fundamental laws of physics to determine the **probability of distribution of interactions.**

- Larger the number of particles to be simulated (Histories) greater is the accuracy of prediction.
- But this increases computational time. Hence only a small randomly selected sample is simulated.
- This predicts the average behavior of all particles in the beam

Types of MC codes

- Electron Gamma shower version4 (EGS 4)
- PENELOPE
- Monte Carlo N Particle (MCNP)
- PEREGRINE
- ETRAN/ITS

Dose Calculation Algorithms

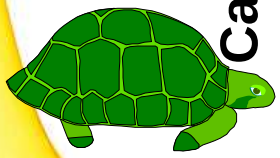


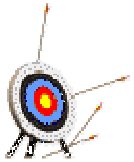
Pencil Beam

Superposition/Convolution

Monte Carlo

Calculation Speed



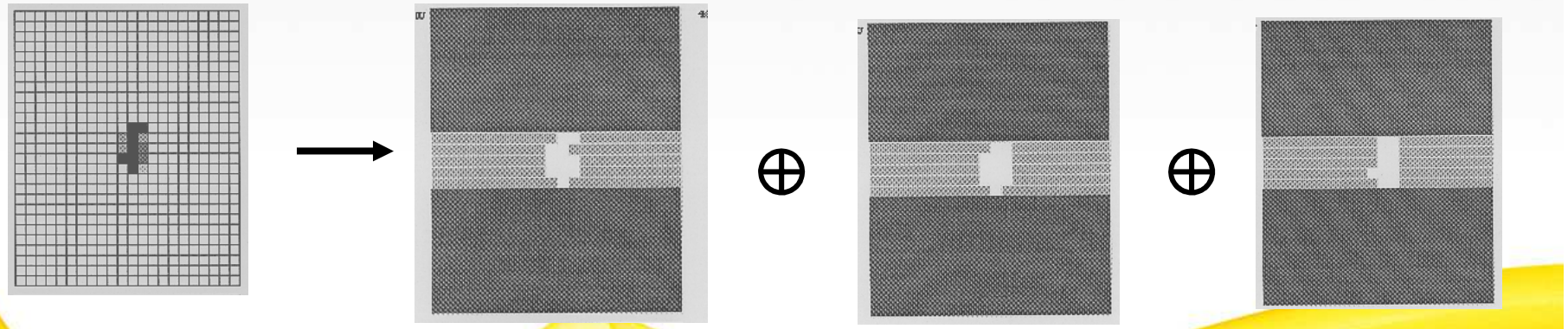


Calculation Accuracy

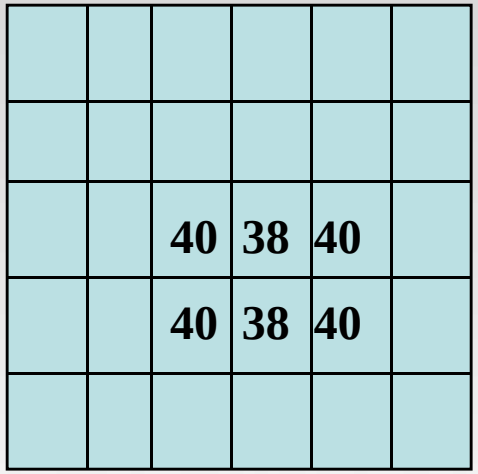
Courtesy: Jeff Siebers, VCU

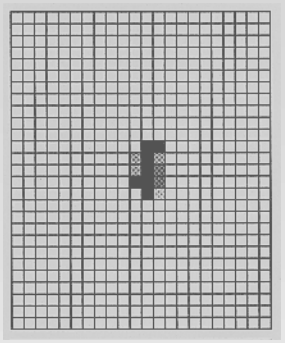
IMRT - Delivery - Static

- Converting Intensity Map to Leaf positions (‘Translator’)

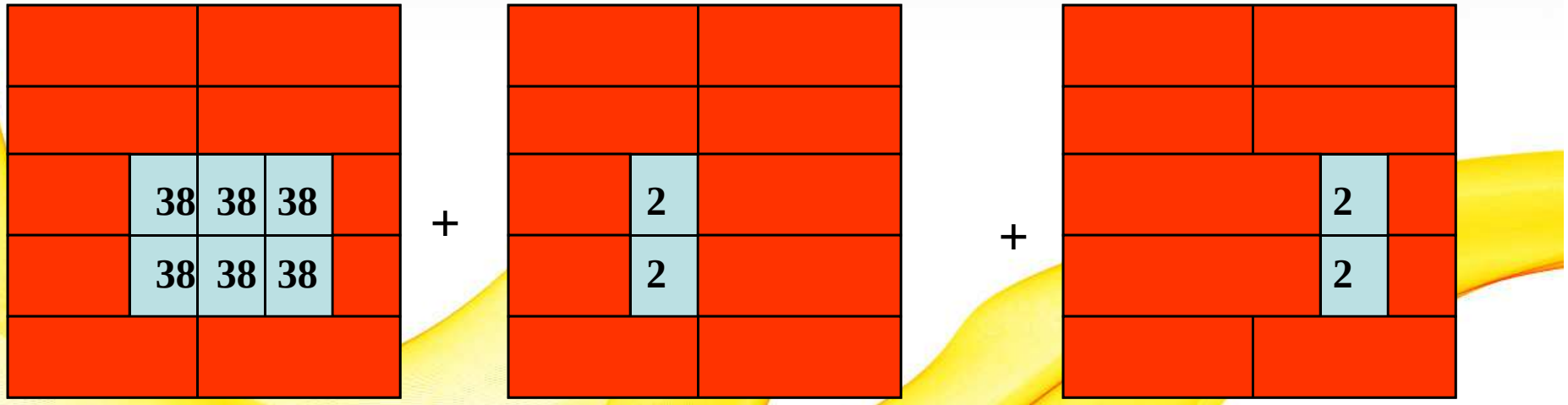


Beam Intensity Map





3 MLC Segments



DOSE CONSTRAINTS

Head & Neck

Organ	Mean Dose	Max Dose	Median Dose	Volume based
Parotid Gland	26Gy	NA	NA	50% vol<30Gy or 20cc of both glands<20Gy
Eye/Retina	NA	50Gy	NA	NA
Optic Chiasm	NA	54Gy	NA	NA
Mandible	NA	70Gy	NA	<1% vol >70Gy
Brainstem	NA	54Gy	NA	<1% vol >54Gy
PRV Brainstem	NA	60Gy	NA	<1% vol>60Gy
Spinal Cord	NA	45Gy	NA	<1% vol >45Gy
PRV Spinal Cord	NA	50Gy	NA	<1% vol >50Gy
Lacrimal Gland	30Gy	NA	NA	

Head & Neck

Organ	Mean Dose	Max Dose	Median Dose	Volume based
Lens	NA	5-10Gy	NA	NA
Optic Nerve	NA	54Gy	NA	NA

Lung

Organ	Mean Dose	Max Dose	Median Dose	Volume based
Spinal Cord	NA	46Gy	NA	1% vol<48Gy
PRV S C	NA	50Gy	NA	1% vol <50Gy
Total Lung-PTV	NA	NA	NA	V_{20Gy}<40%(RT alone) V_{20Gy} <35%(CTRT) V_{20Gy}<20%(CTRT-Sx)
Heart	NA	NA	NA	V_{50Gy}<50%
Oesophagus	34Gy	NA	NA	Length receiving 60Gy<16cm
Brachial plexus	NA	66Gy	NA	None

Liu et al; IJROBP 2004
Lee et al, IJROBP 2003

Gynecological Malignancies

Organ	Mean Dose	Max Dose	Median Dose	Volume based
U Bladder	45-48Gy	50Gy	45-48Gy	50% vol<35Gy; 66% vol<40Gy
Rectum	42-45Gy	50Gy	42-45Gy	50% vol<35Gy; 66% vol<40Gy
Small bowel	NA	50Gy	NA	30% vol<35Gy; 50% vol,25Gy
Femoral head	NA	50Gy	NA	50% vol<40Gy
Bone marrow	NA	NA	NA	V10 <90%; V20<75%

Mundt et al; IJROBP 2003

Prostate

Organ	Mean Dose	Max Dose	Median Dose	Volume based
Urinary Bladder	45-48Gy 48Gy	50Gy	45-	V_{80} <15%
				V_{75} <25%
				V_{70} <35%
				V_{65} <50%
Rectum	42-45Gy 45Gy	50Gy	42-	V_{75} <15%
				V_{70}<25%
				V_{65}<35%
				V_{60}<50%
Small bowel	NA	50Gy	NA	V_{45} <150cc

(RTOG 9406; IJROBP 2002)

Prostate

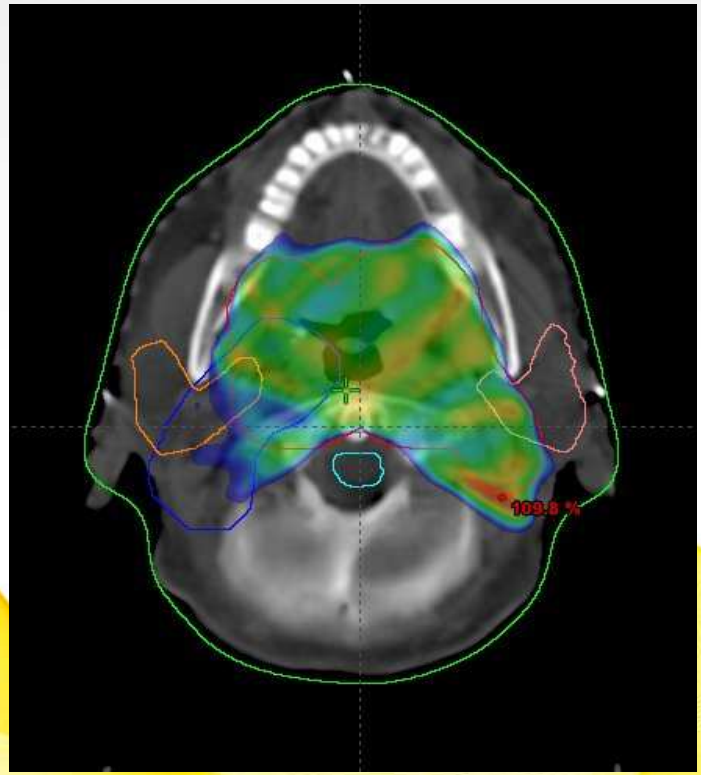
Volume	Target	Absolute constraints	Relative constraints
CTV1	Prostate, prox SV	$D_{100\%}$≥100% pres dose	None
PTV1	CTV1+8mm except 5mm posteriorly	$D_{95\%}$≥100% pres dose D_{max}<17% pres dose $V_{<65Gy}$<1%	
PTV2	Distal SV+8mm	$D_{95\%}$≥100% pres dose	None
PTV3	LN+8mm	$D_{95\%}$≥100% pres dose	None
Rectum	From sigmoid flexure to ischial tuberosity	$V_{<65Gy}$<17% $V_{<40Gy}$<35%	90% isodose line encompasses no more than half width on any axial cut, 50% isodose line does not encompass full rectum width
Bladder	Partially filled entire bladder	$V_{<65Gy}$<25% $V_{<40Gy}$<50%	None
Femoral heads	Right and left femoral heads between trochanters	V_{50Gy}<10% for each (FCCC, Philadelphia, US)	None

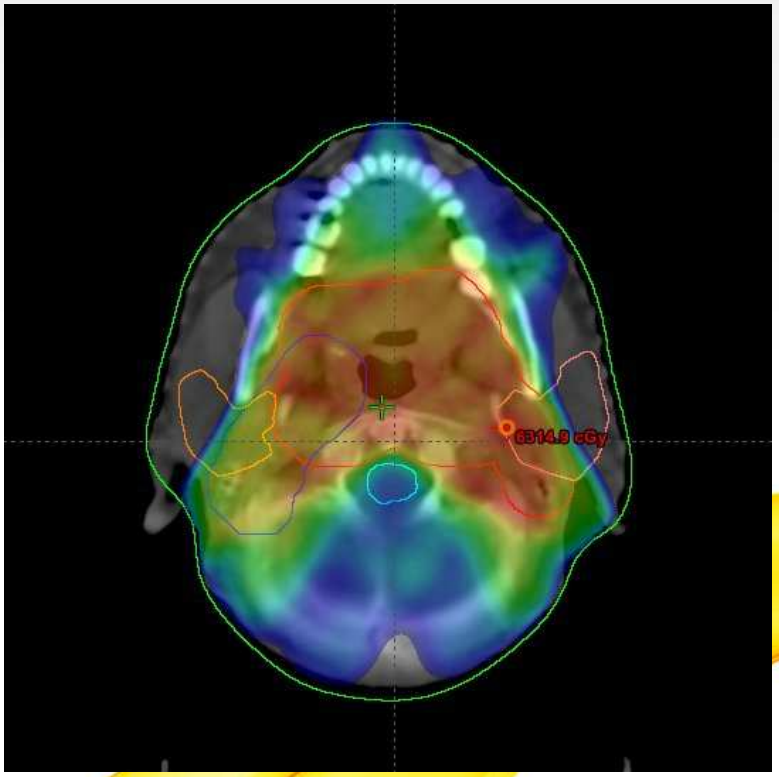
Plan evaluation

- Dose statistic spreadsheet
  - To assess whether the plan acceptance criteria are met
- Dose- volume histogram(Quantitative)
  - To evaluate fraction of the defined volumes receiving high and low doses
- Slice by slice evaluation(Qualitative)
  - Dose conformity
  - Hot and cold spots

Qualitative evaluation

Isodose and dose colour wash display

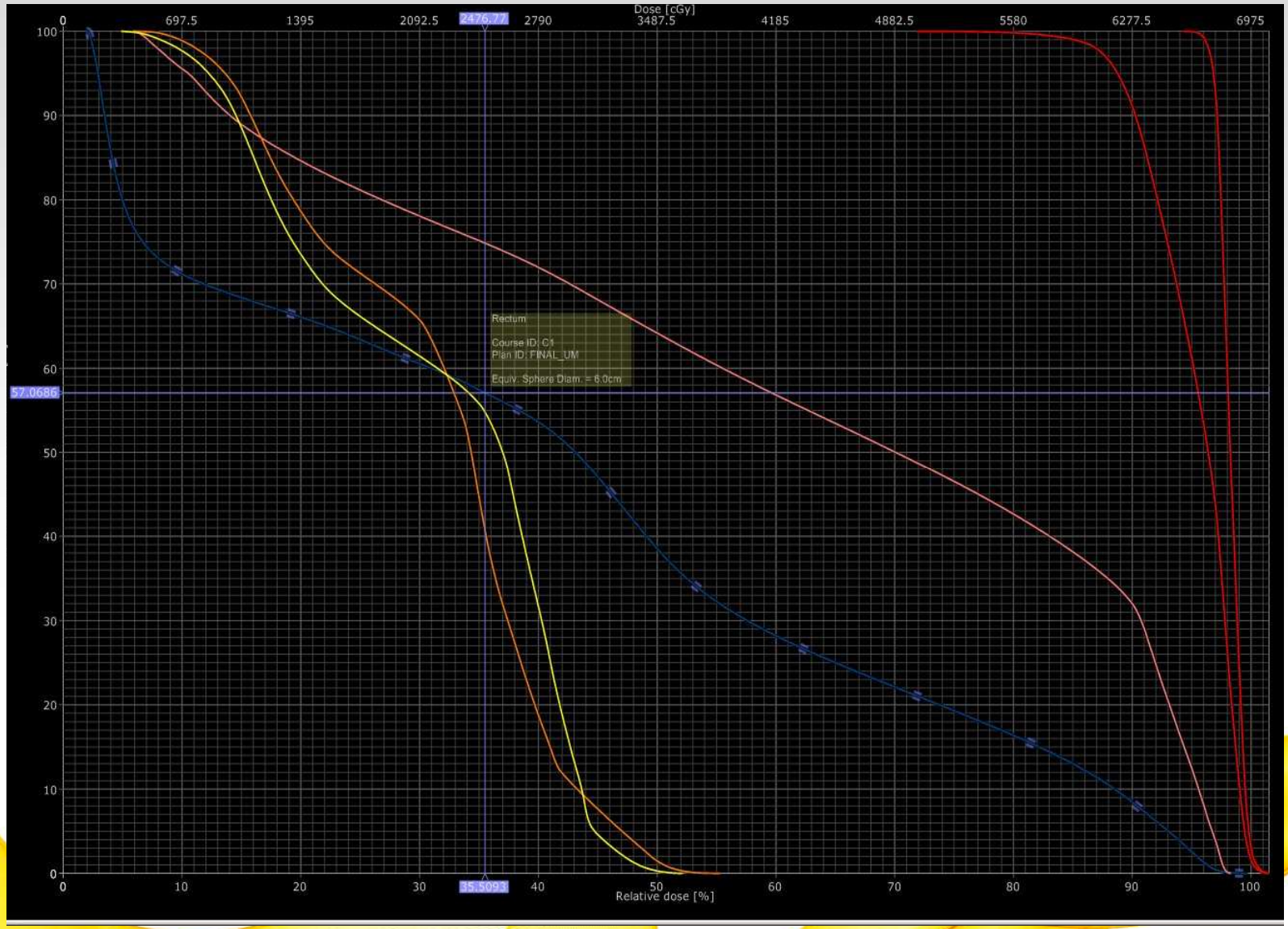




Quantitative evaluation

Cumulative DVH

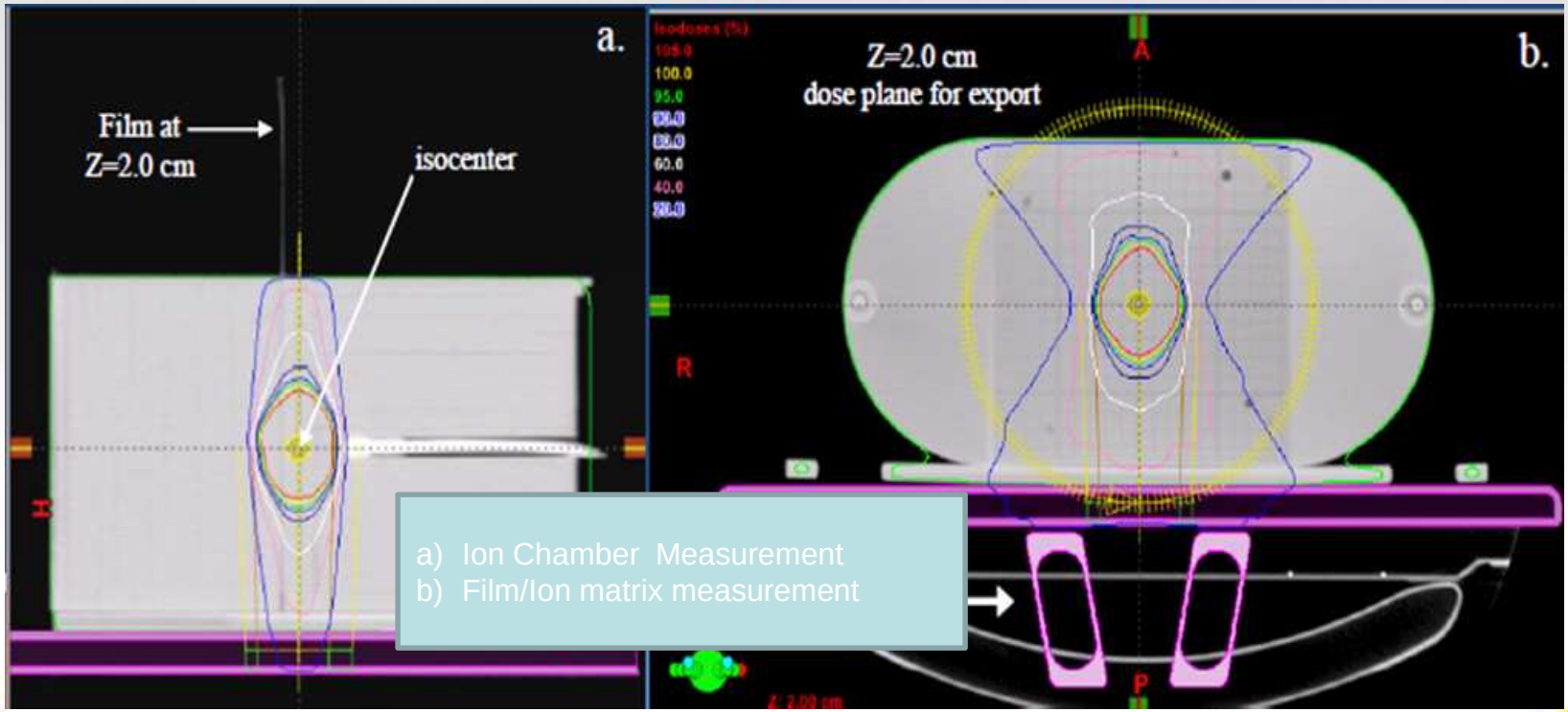
- Plot of entire volume of anatomical structure with specified dose or higher dose.
- Precision of DVH depends upon density of the sampling grid used.
  Coarse grid: Uncertain dose information
  Fine grid: Large computational time.
- Highlights hot and cold volumes at a glance.


Dose [cGy]
0
697.5
1395
2092.5
2476.77
2790
3487.5
4185
4882.5
5580
6277.5
6975
100
90
80
70
60
57.0686
50
40
30
20
10
0
Rectum
Course ID: C1
Plan ID: FINAL_UM
Equiv. Sphere Diam. = 6.0cm
0
10
20
30
35.5093
40
50
60
70
80
90
100
Relative dose [%]

Patient-Specific QA

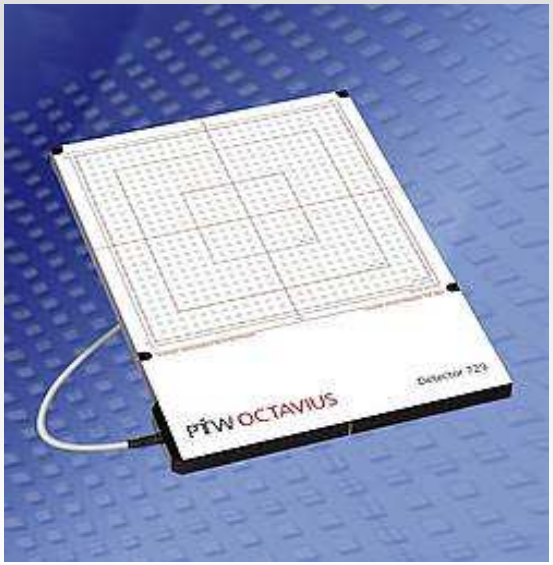
- Comparison of the absorbed-dose distribution in a phantom with that calculated by the treatment planning computer for the same irradiation condition
- Measurement of the intensity pattern from individual beams for a specific patient.
- Measurement of the intensity pattern from individual beams for a specific patient.
- Measurements of absorbed dose in phantom of the beam-intensity pattern planned for a specific patient

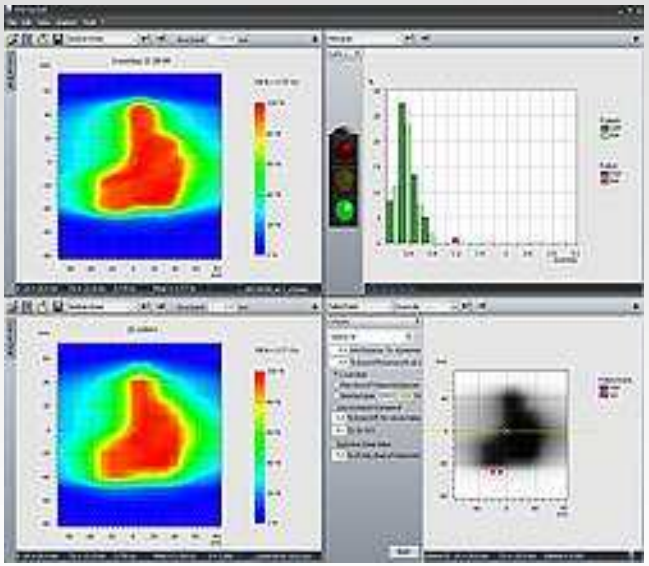
Film and Ion Chamber QA



a) Ion Chamber Measurement
b) Film/Ion matrix measurement

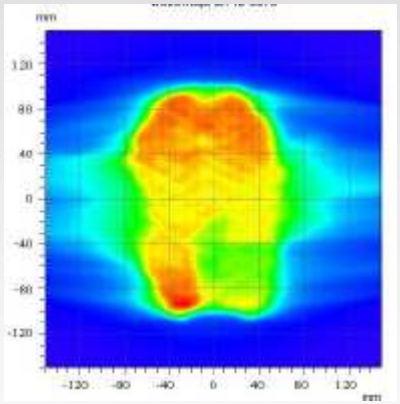
PTW OCTAVIUS® II

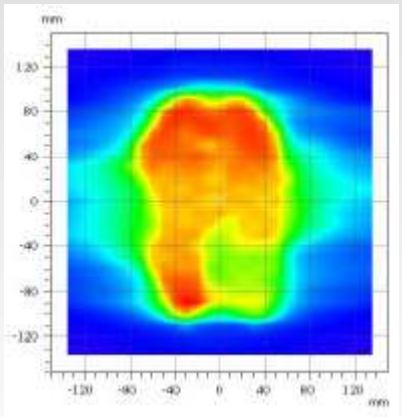


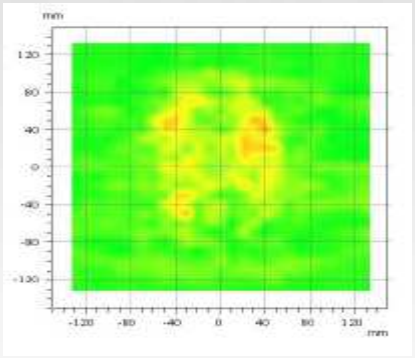


Detector size:	0.5 cm x 0.5 cm x 0.5 cm (0.125 cm^3)
Detector spacing:	10 mm center-to-center, 5 mm edge-to-edge
Max. field size:	27 x 27 cm^2
Max. measurement points:	2916 (four measurements)
Reproducibility:	≤± 0.5%
Resolution:	1 mGy or 1 mGy/min
Measurement range:	(0.5 ... 45) Gy/min

Gamma Value







Gamma 2D - Parameters

3.0 mm Distance- To- Agreement
3.0 % Dose Difference with ref. to Max. dose of measured data set
Use increased tolerance of 5.0 % Dose Diff. for values below 0.1 Gy (or AU)
Suppress doses below 2.0 % of max. dose of measured data set

Statistics

Number of Dose Points	729
Evaluated Dose Points	729 (100.0 %)
Passed	728 (99.9 %)
Failed	1 (0.1 %)
Result	99.9 % (Green)

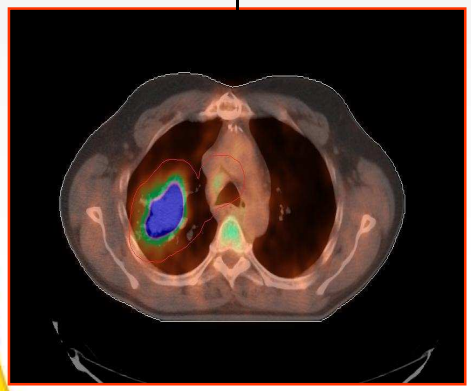
Settings

Treatment Delivery

- Patient alignment verification using portal imaging is necessary
- Treatments may be delivered remotely or automatically under computer control

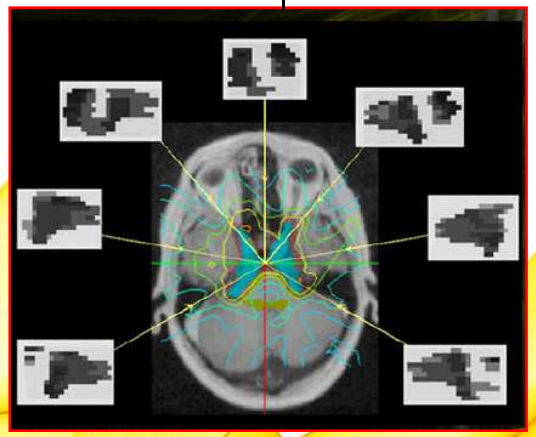
Local control

Identification of the target



Delivery of radiation

Excellent dose distribution



Precision targeting

?

IGRT

Imaging for treatment verification

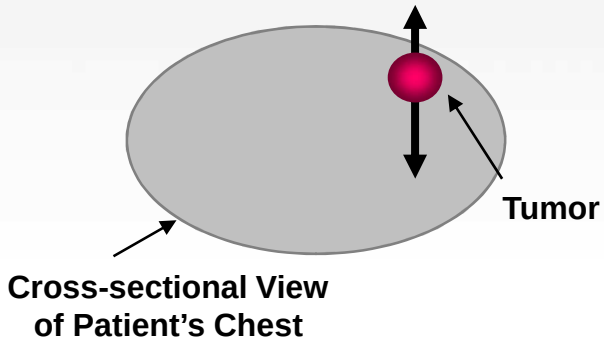
1980's	• Port film
1990's	• Emergence of MV portal imagers • In-room ultrasound localization • Marker-based localization • Fluoroscopic tracking
2000's	• Flat panel imaging (EPID) • KV digital imaging • CT – on rail • KV-CBCT • MV-CBCT

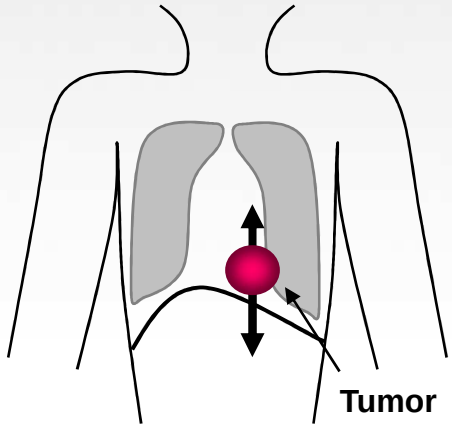
Goal and Clinical benefit

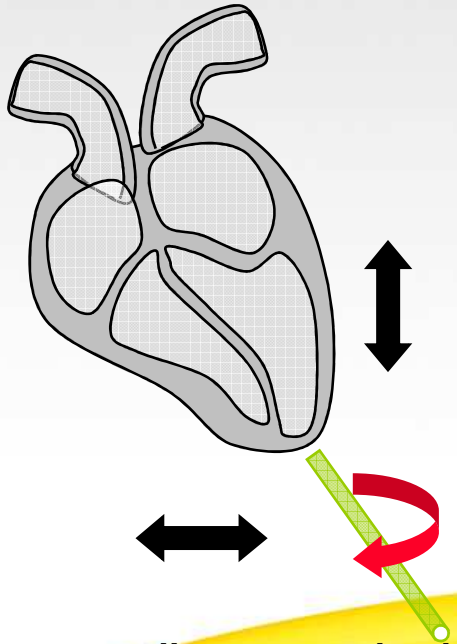
- To improve the accuracy of the radiation field placement
- To reduce the exposure of healthy tissue during radiation treatment

Tumor Motion During Respiration

- All tumor motion is complex







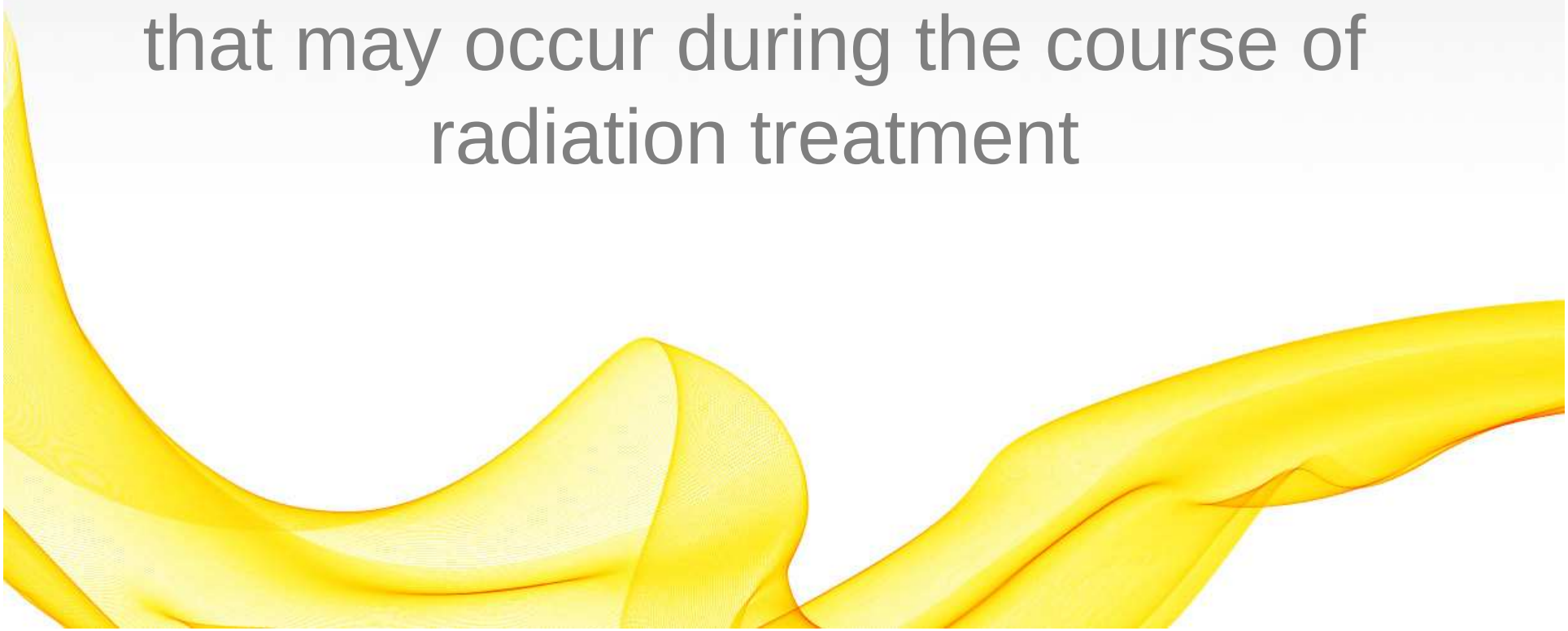
Some motion is mostly
Anterior / Posterior

Some motion is mostly
Superior / Inferior

All tumor motion is
Complex

Adaptive Radiotherapy

The clinical benefit for the patient is the ability to monitor and adapt to changes that may occur during the course of radiation treatment



Adaptive radiotherapy (cont.)

The courses of inaccuracies may include :

- Tumor shrinkage during the course of treatment
- Patient loss weight during the course of treatment
- Increase hypoxia during the course of treatment

Adaptive radiotherapy (cont.)

Allows us to correct for :

- Set up errors
- Inter-fraction organ motion :
  Inaccurate set up because of organ changes in each fraction
- Intra-fraction motion : Organ motion during treatment

Adaptive radiotherapy

Adaptive

- Set up errors
- Inter-fraction organ motion

Gating

- Intra-fraction motion

IGRT

Two-dimensional (2D) IGRT would include :

- Matching planar kilovoltage (kV) radiographs fluoroscopy
- CBCT with two orthogonal images
- megavoltage (MV) images with digital reconstructed radiographs (DRRs) from the planning CT.

IGRT

Three-dimensional (3D) IGRT would include :

- localization of a cone-beam computed tomography (CBCT)
- computed tomography (CT) data set from planning

Image-Guided RT Technologies

Ultrasound
BAT
SonArray
I-Beam
Restitu

Video-Based
Video Subtraction
Photogrammetry
AlignRT
Real-Time Video-Guided IMRT

Related Technologies
RPM gating/4DCT
Optical-guided Approaches

Planar X-Ray
EPID
CyberKnife
Novalis
RTRT
Gantry-Mounted
- Protoype
  - Tohoku, IRIS
- Commercial
  - Varian OBI
  - Elekta Synergy

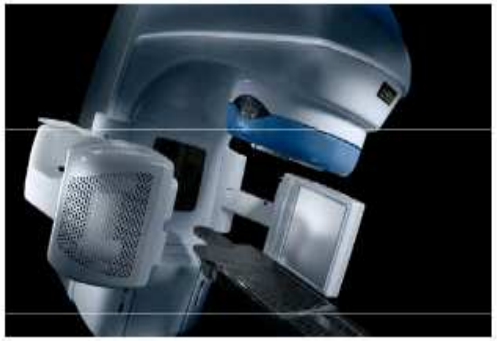
Volumetric
In-Room CT
- FOCAL, MSKCC
- CT-on-Rails
  - Primaton
  - Varian ExaCT

Tomotherapy
MV Cone Beam CT
- Siemens

kV Cone Beam CT
- Mobile C-arm
- Varian OBI
- Elekta Synergy
- Siemens In-Line

VOLUMETRIC (3D) IGRT

Siemens CTVision™



Varian Trilogy OBI®

Novalis Tx™

Siemens Artiste™
KVision

TomoTherapy® (HiART)

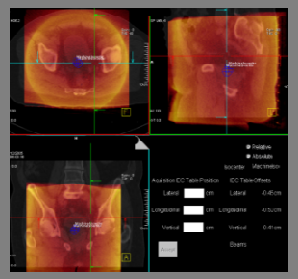
Elekta Synergy™
VolumeView

Elekta Axesse™

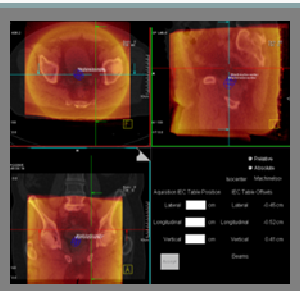
IGRT workflow ...

Patient positioned on the table in Tx. Position

Acquire scan using OBI



3D image fusion



Automatic table offset calculation

Apply offset

Treatment Execution

Process Flow
Planar IGRT

Day 1
MDs and RTTs Meet at Control Console
Discuss alignments and couch shifts

Day 5 through Completion

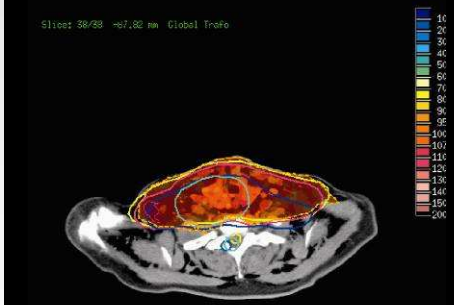
All Shifts <=1mm

Make no shifts and Treat

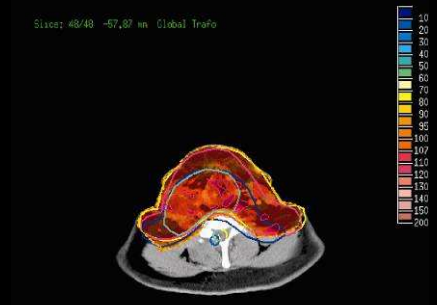
LR shift > 3mm
SI or AP Shift > 5 mm

Call MD

CTVision clinical case – Head & Neck

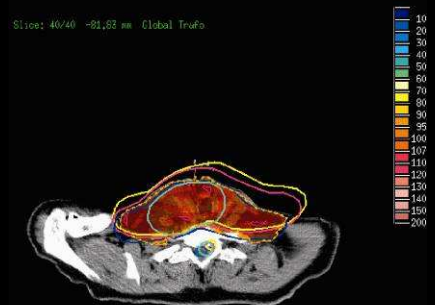


1a

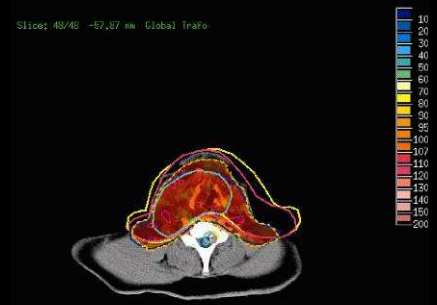


1b

Original dose distribution 1a and 1b



2a



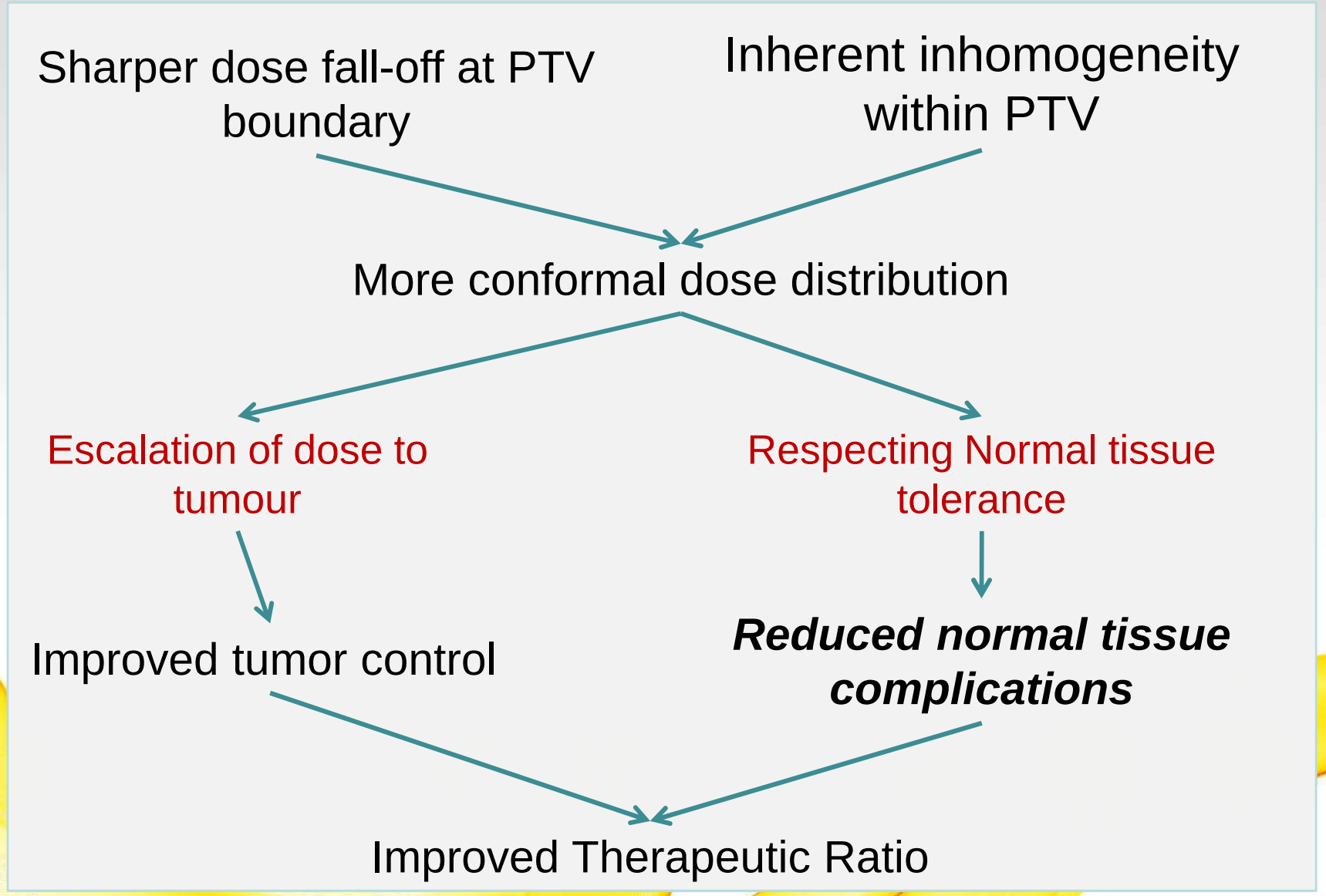
2b

Adapted dose distribution after resorption of air and weight loss 2a and 2b

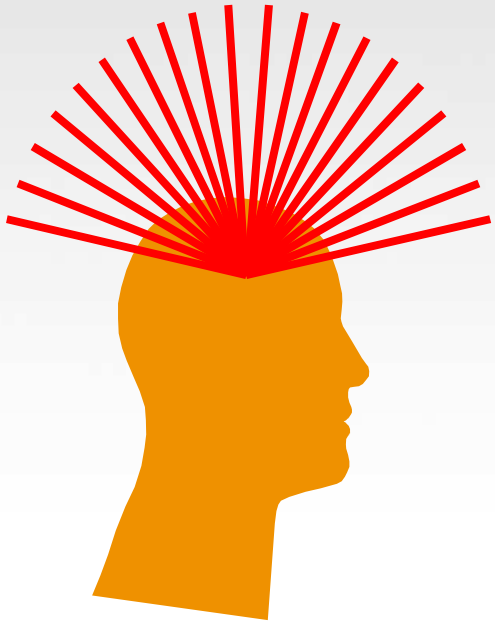
“One of the most important advantages of CTVision in-room CT is clearly the ability to use scans for both position control and as a basis for another treatment plan.”

M.W. Münter MD,
A. Jensen, MSc,
P. Huber, MD, PhD
The German Cancer Research Center
Heidelberg, Germany

Radiobiological Advantage of IMRT



STEREOTACTIC RADIOSURGERY



STEREOTACTIC RADIOSURGERY

- “Stereo” Greek: Solid or 3dimensional
- “tact” Latin: to touch
- Stereotactic : 3 dimensional arrangement to touch
- Stereotactic Radiosurgery :
  - Technique of delivering high dose radiation to a specific target while delivering minimal dose to surrounding tissue

History of SRS

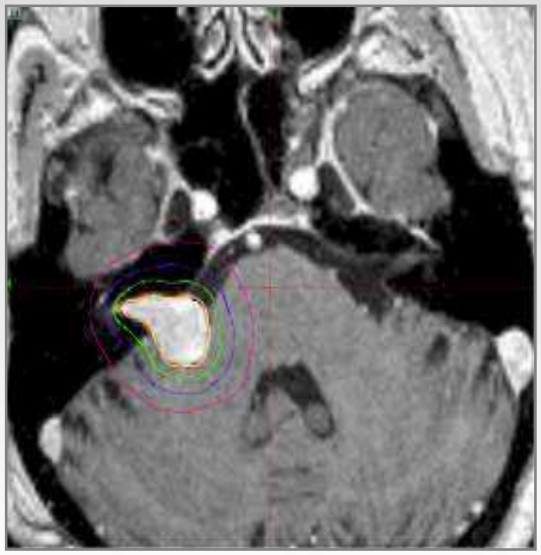
Year	Author	Location	Event
1982	Betti Colombo	Buenos Aires Vicenza	Independent development of a system adapting LINACs for radiosurgery
1986	Lutz/ Winston	JCRT	Development of LINAC based SRS based on common stereotactic frame
1987	Lundsford	Pittsburgh	First Gammaknife installed in the US
1991	Friedman/ Bova	Florida	Development of a more reliable technique for highly conformal radiosurgery
1991	Lax Blomgren	Karolinska	First to propose extending SRS outside of the skull
1992	Loeffler/ Alexander	Boston	First commercially built dedicated SRS LINAC (Varian-SRS)
1993	Laing	Boston	Gill-Thomas-Cosman relocatable frame

History of SRS

Year	Author	Location	Event
1994	Lax Blomgren	Karolinska	Stereotactic treatments of abdominal tumors (1994)
1994	Adler	Stanford	First clinical use of prototype of Cyberknife
1995	Hamilton Lulu	Arizona	First report of SBRT case in North America
2000	Murphy	Stanford	Introduces image-guided radiotherapy
2003	Le/Whyte Timmerman	Stanford Indiana	Lung tumor SBRT
2004	Fuss Salter	San Antonio	SBRT with tomotherapy

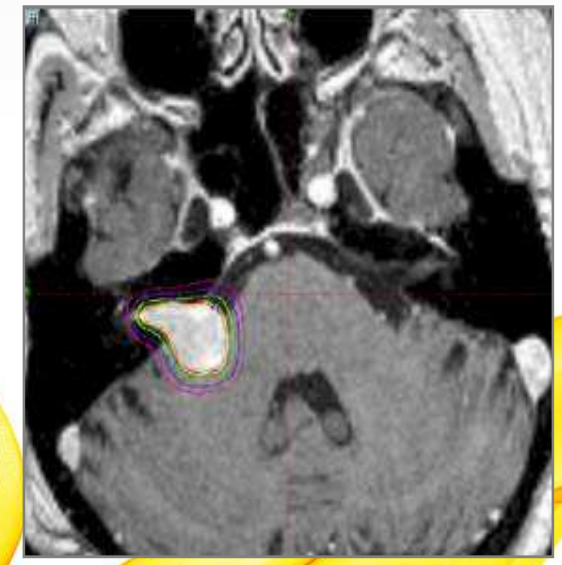
Radiosurgery - Definition

- **Conformity** describes how well the prescription dose is fitted to the target volume



High conformity, low selectivity

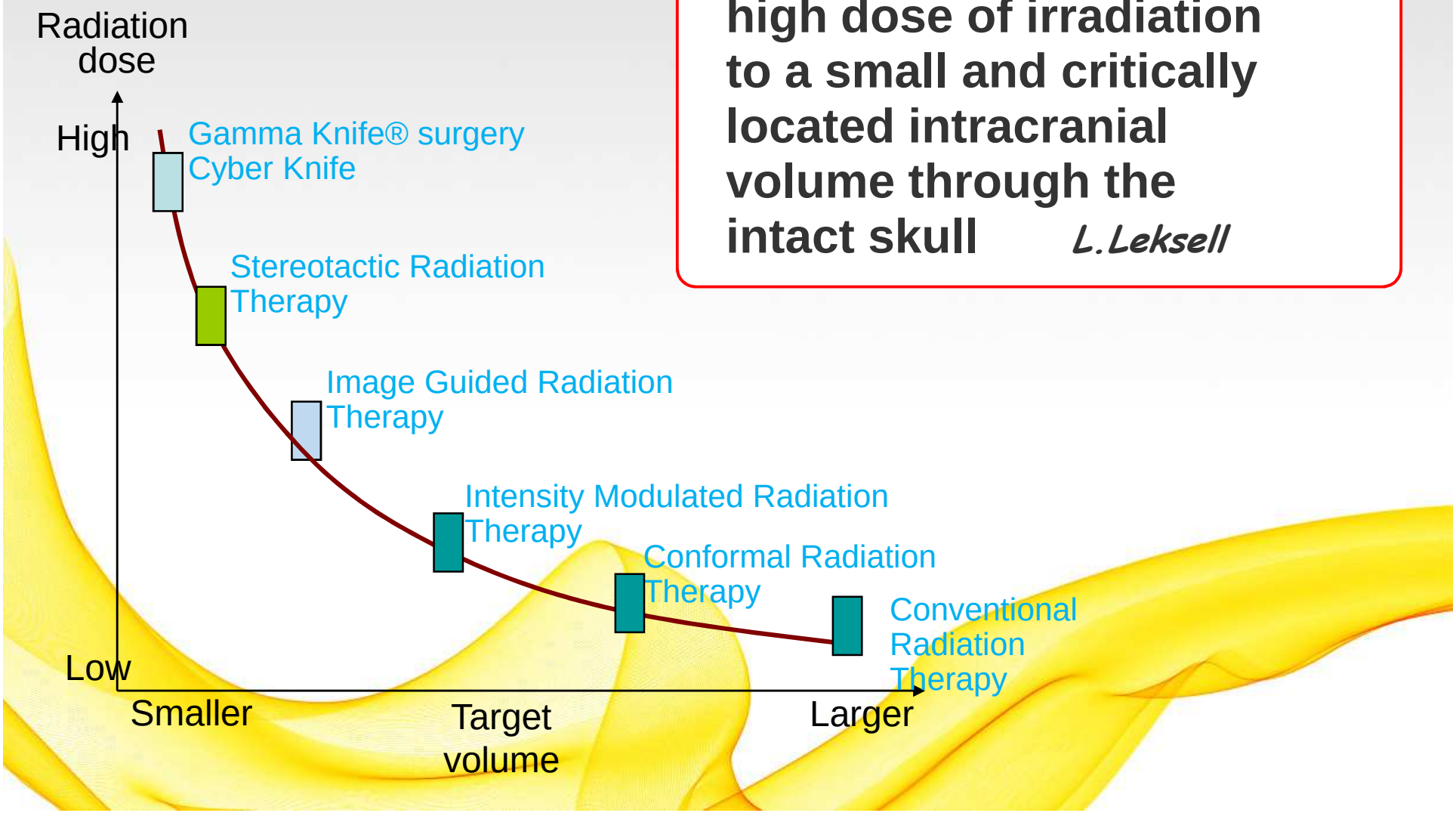
- **Selectivity** also takes irradiation to normal tissue into account



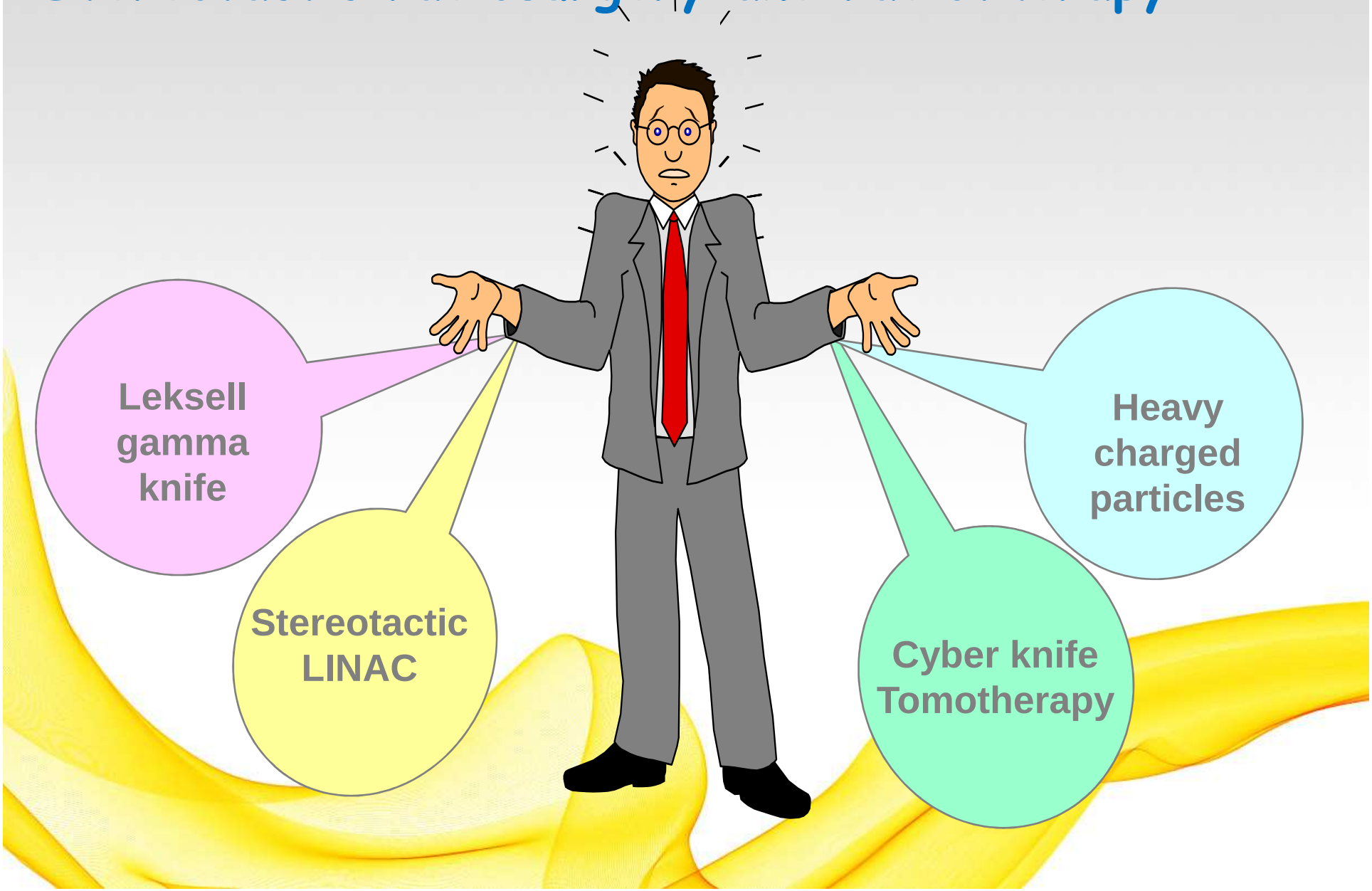
High conformity, high selectivity

Radiosurgery - Definition

The delivery of a single, high dose of irradiation to a small and critically located intracranial volume through the intact skull *L.Leksell*

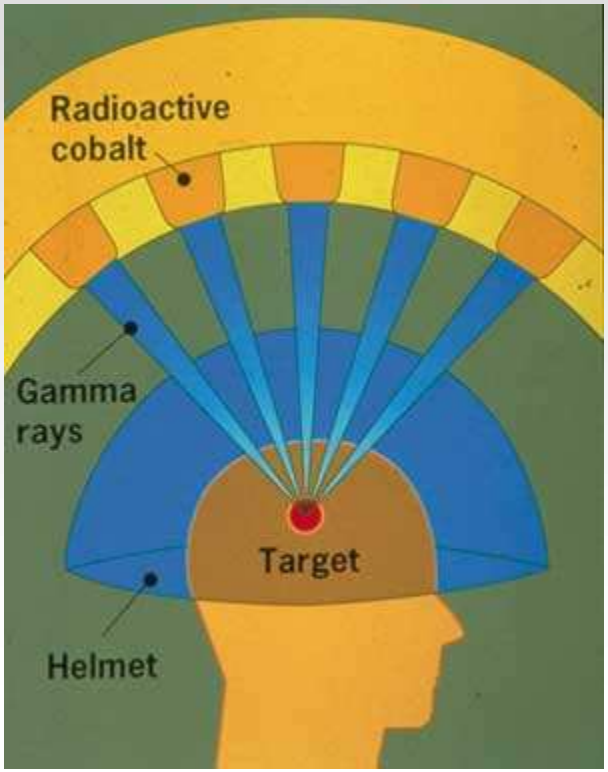


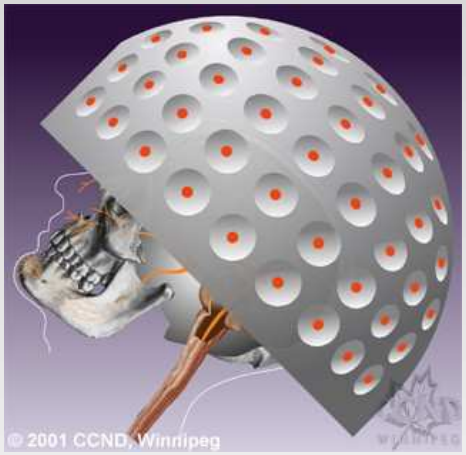
Stereotactic radiosurgery and radiotherapy



GAMMA KNIFE

- The **gamma knife** device contains 201 cobalt-60 sources of approximately 30 curies each
- It is placed in a circular array in a heavily shielded assembly.
- The device aims gamma radiation through a target point in the patient's brain.
- The patient wears a specialized helmet that is surgically fixed to their skull so that the brain tumor remains stationary at target point of the gamma rays.
- Therefore it is also known as the stereotactic surgery.


Radioactive cobalt
Gamma rays
Target
Helmet


© 2001 CCND, Winnipeg

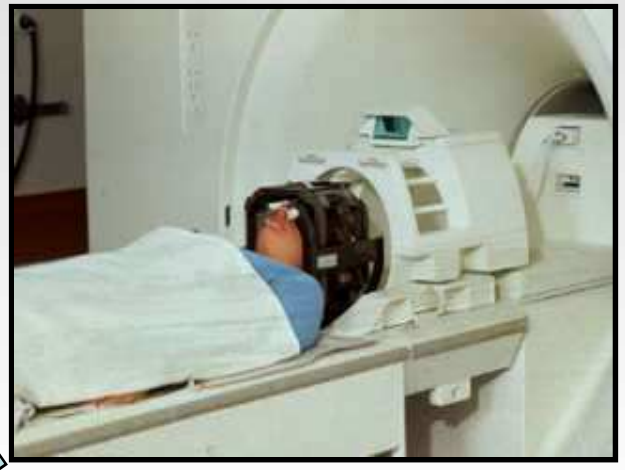

LEKSELL GAMMA KNIFE
LEKSELL GAMMA KNIFE

GAMMA KNIFE

Gamma knife radiosurgery flowchart

1. Frame fixation

2. Diagnostic imaging

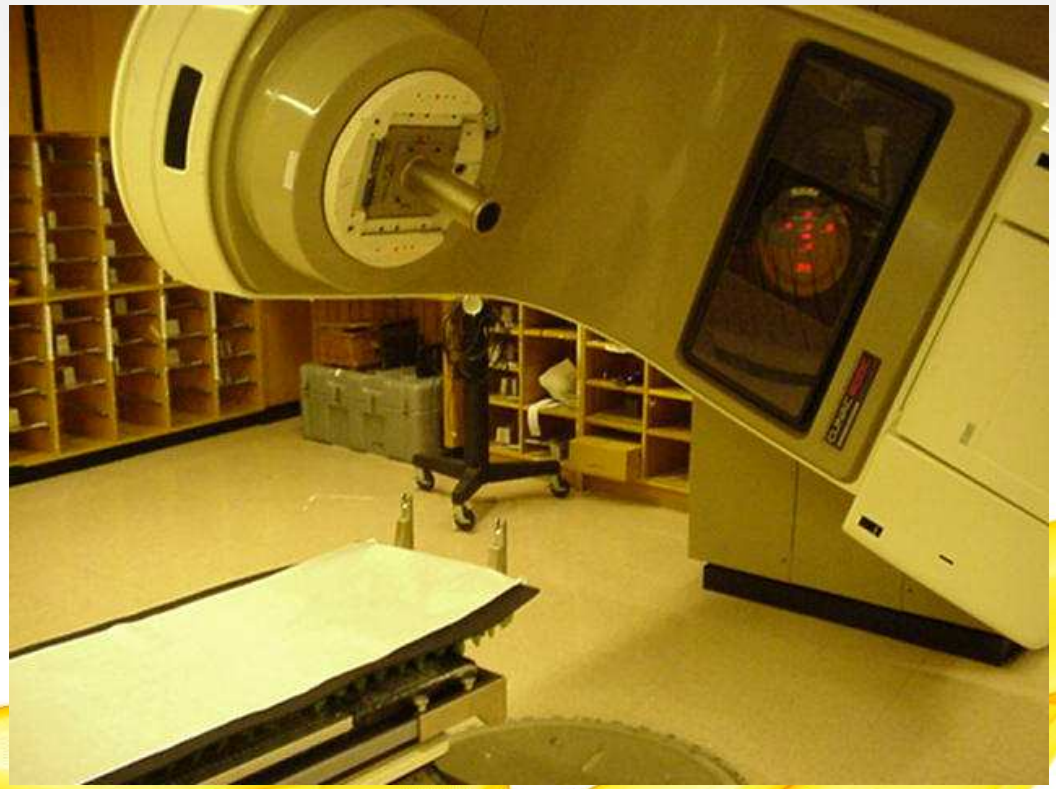


3. Treatment planning

4. Treatment

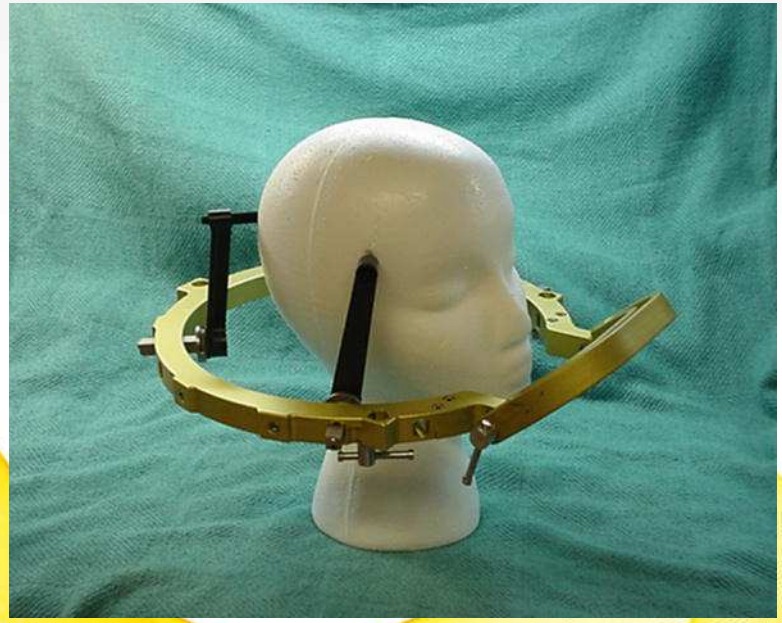
Stereotactic Radiosurgery

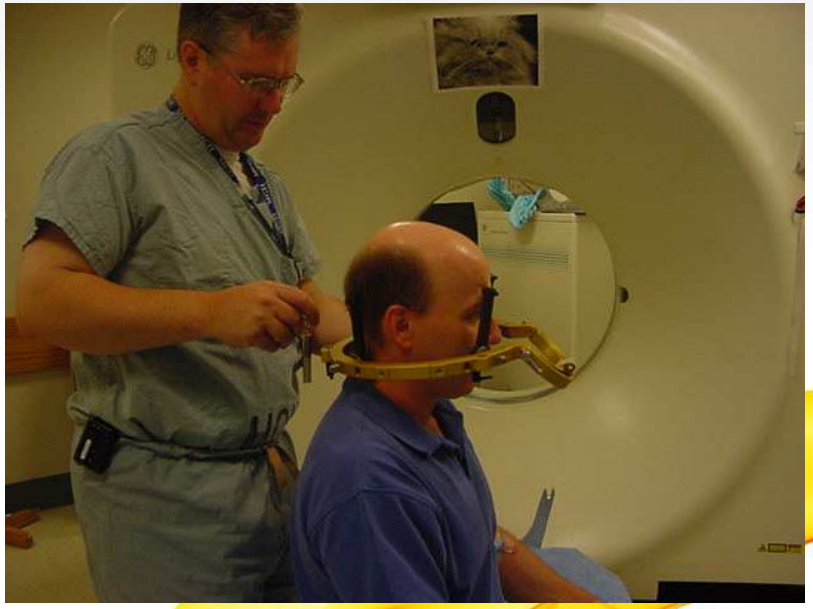
1982: Modified Linear Accelerator



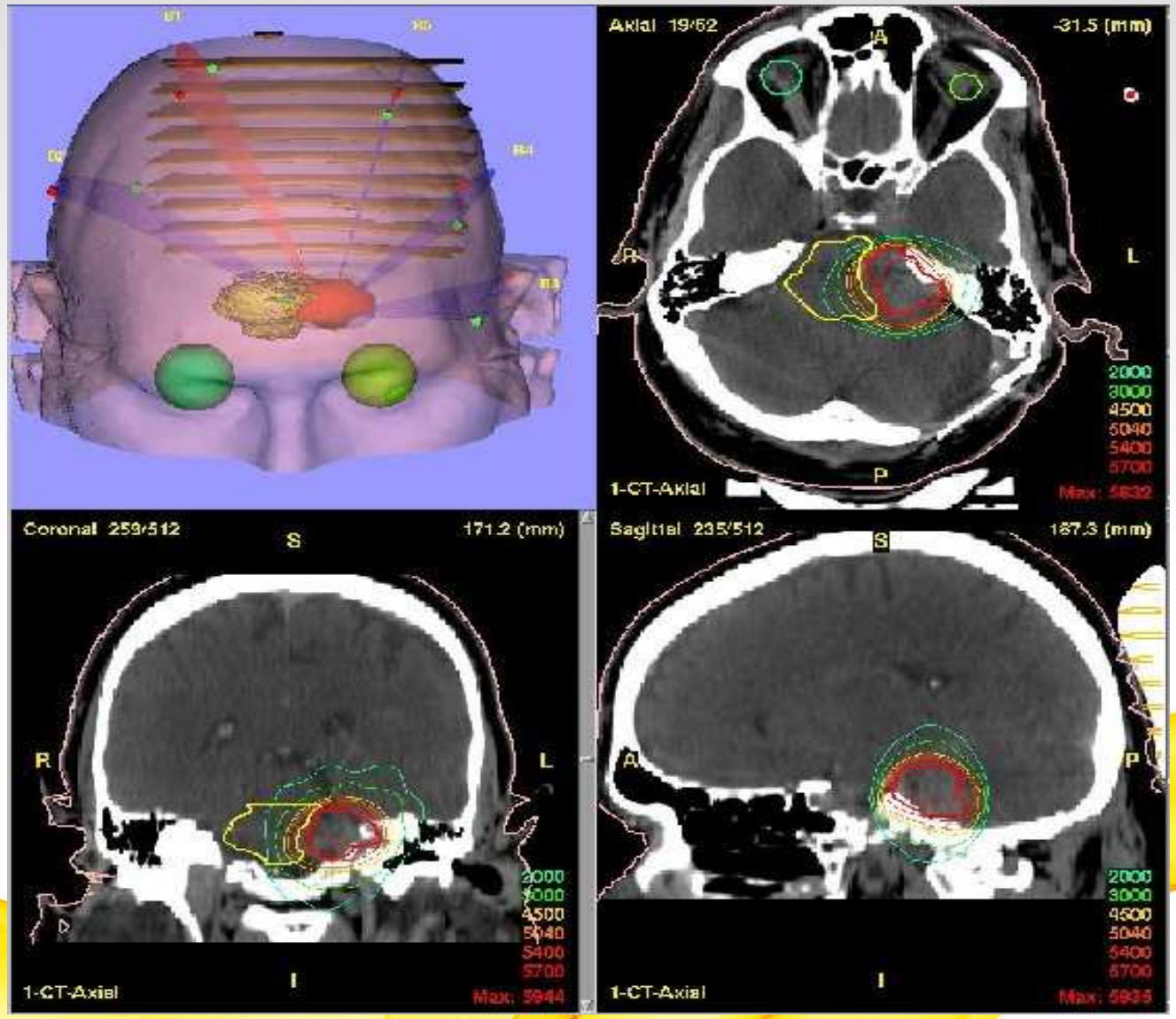
Stereotactic Radiosurgery

SRS Frame Placement



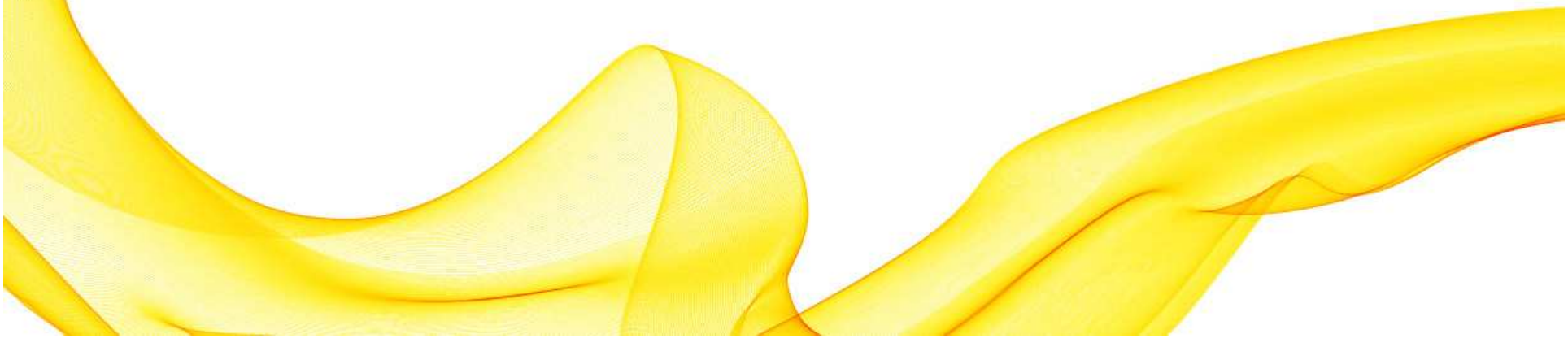


STEROTACTIC RADIATION THERAPY SRT

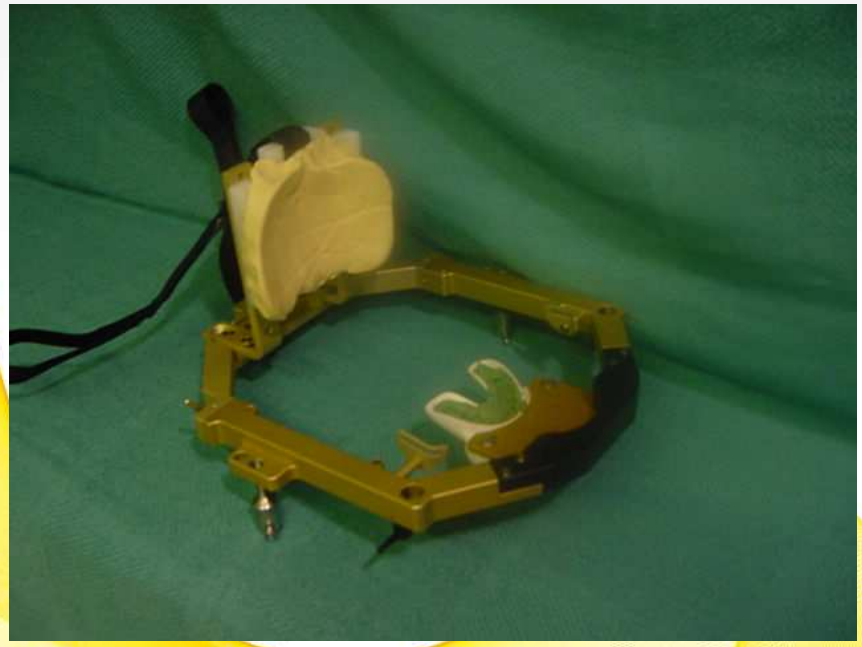


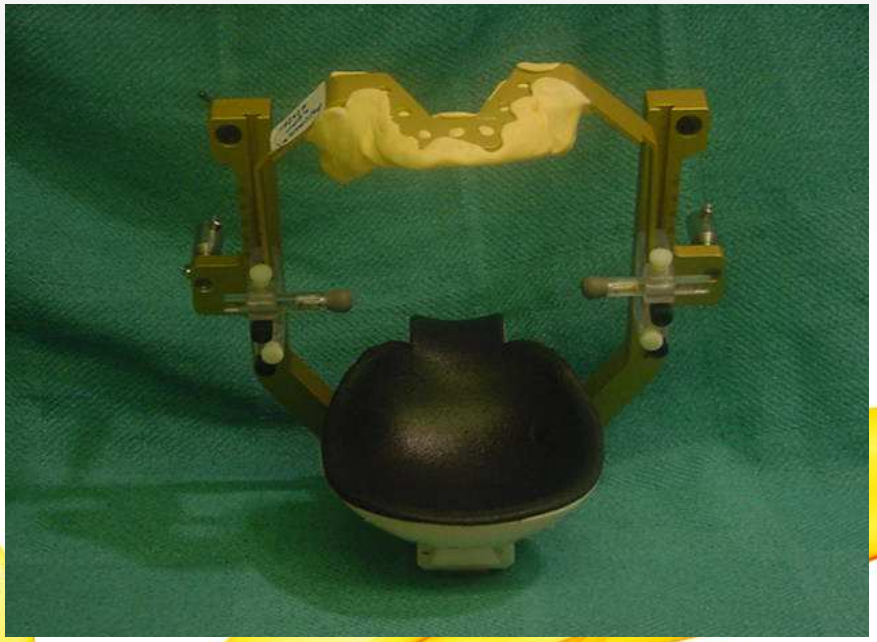
Fractionated Stereotactic Radiation Therapy

Multiple fraction with stereotactic frame



Fractionated Stereotactic Radiation Therapy

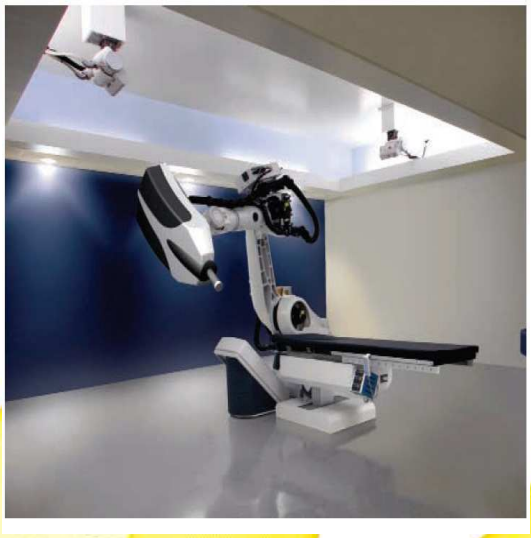




Stereo tactic Body Radio Therapy

Stereo tactic Body Radio Therapy

- Use of external beams to treat lesions of the body with “surgical” doses and high precision tumor identification and relocalization employing “stereotactic” image guidance or implanted fiducials.



SBRT REQUIRES:

- Higher confidence in tumor targeting
- Reliable mechanisms for generating focused, sharply delineated dose distributions
- Reliable accurate patient positioning accounting for target motion related to time dependent organ movement

SBRT: who started it?

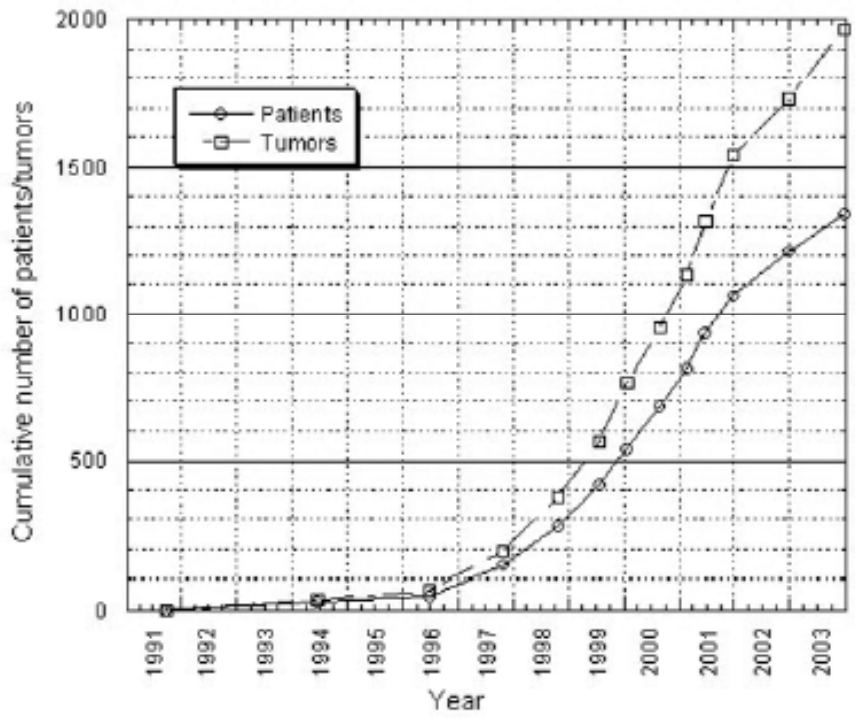


TABLE 2 Anatomic Distribution of 1965 Tumors That Have Been Treated with Stereotactic Body Radiation Therapy at the Karolinska Hospital from 1991 to 2003.

Organ	*No. Tumors*
Lungs	997
Mediastinum	78
Liver	484
Pancreas	149
Suprarenal glands	30
Abdomen[a]	118
Skeleton	25
Miscellaneous[b]	46

[a]Mainly kidneys and para-aortic regions.
[b]Pelvic area, muscles, and so forth.

Answer: Blomgren and Lax, Karolinska Institute, Stockholm, Sweden

* Slide courtesy of Brian Kavanagh / University of Colorado

SBRT: who started it?

Prelude to a New Therapeutic Paradigm: The Clinical Transition from Intracranial to Extracranial Stereotactic Radiation Therapy

Ingmar Lax and Henric Blomgren

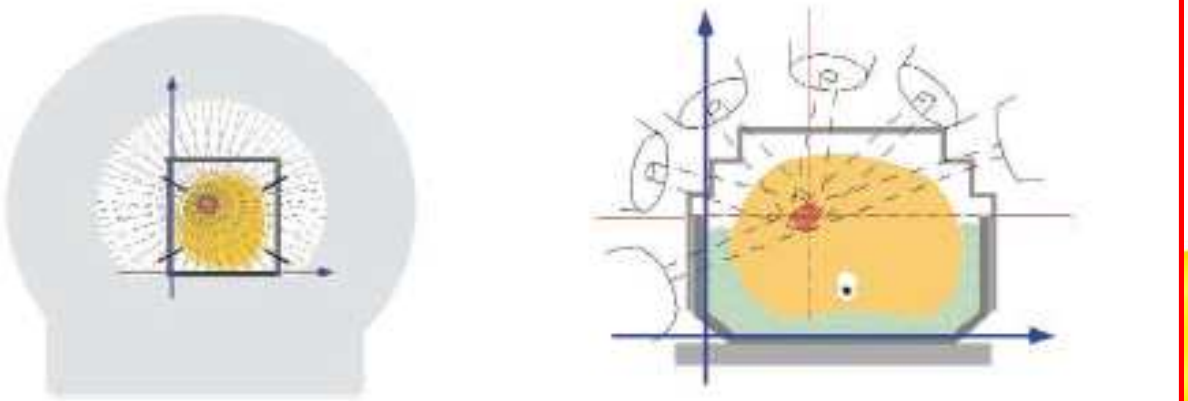


FIGURE 1. The left panel shows a schematic drawing of intracranial stereotactic radiosurgery with the Gamma Knife (Elekta, Norcross, GA). The stereotactic frame is fixed with screws into the skull. The right panel shows a schematic drawing of extracranial stereotactic radiation therapy with linear accelerator. The patient is fixed in the stereotactic body frame.

* Slide courtesy of Brian Kavanagh / University of Colorado

Conventional vs SBRT

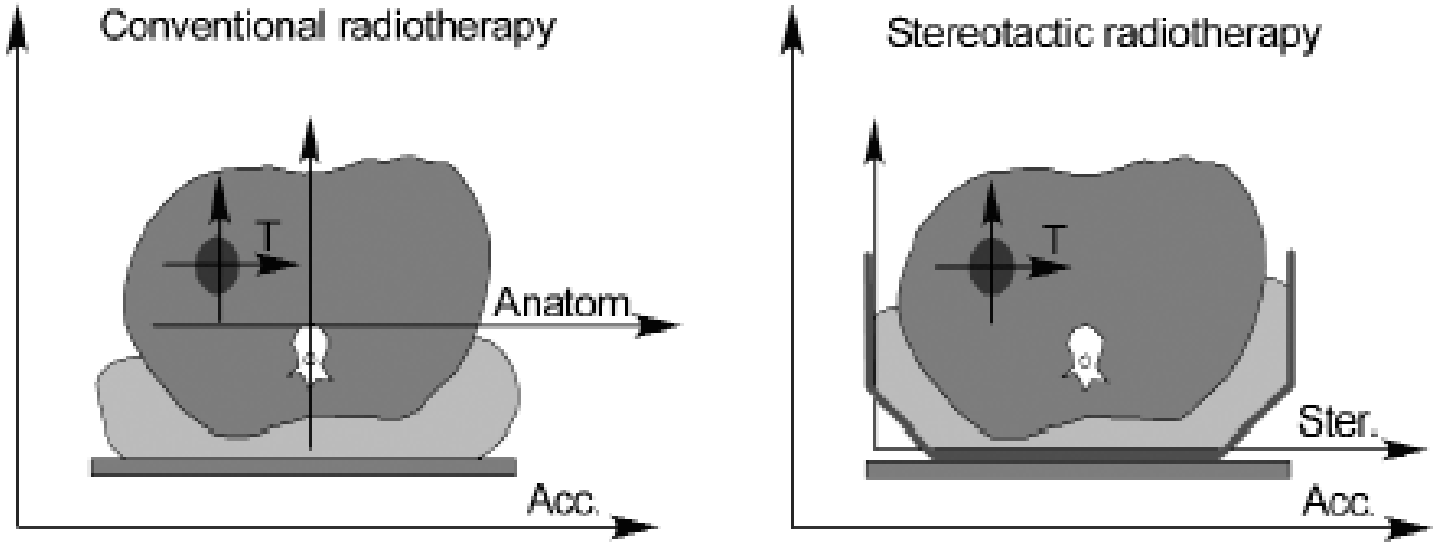
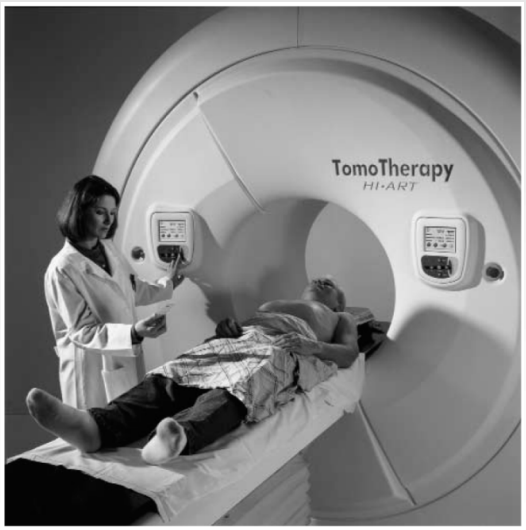
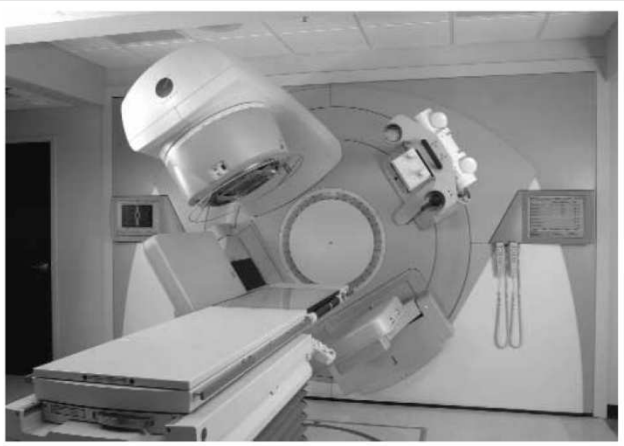


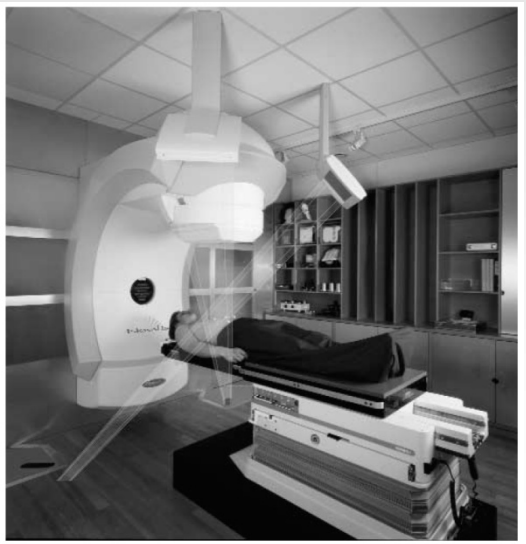
FIGURE 2. Illustration of coordinate systems used in conventional radiotherapy (left) and stereotactic body radiation therapy (right).

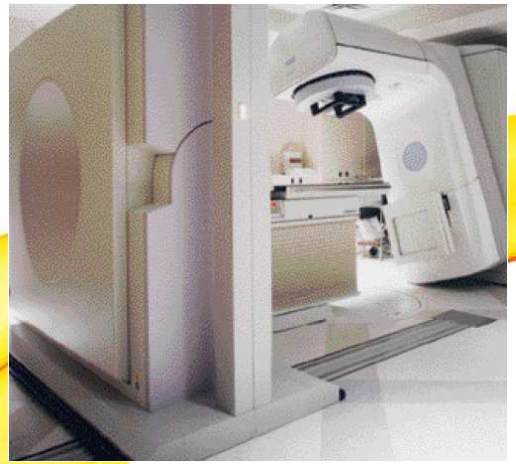
*** Slide courtesy of Brian Kavanagh / University of Colorado**

Linear Accelerators with features especially suitable for SBRT

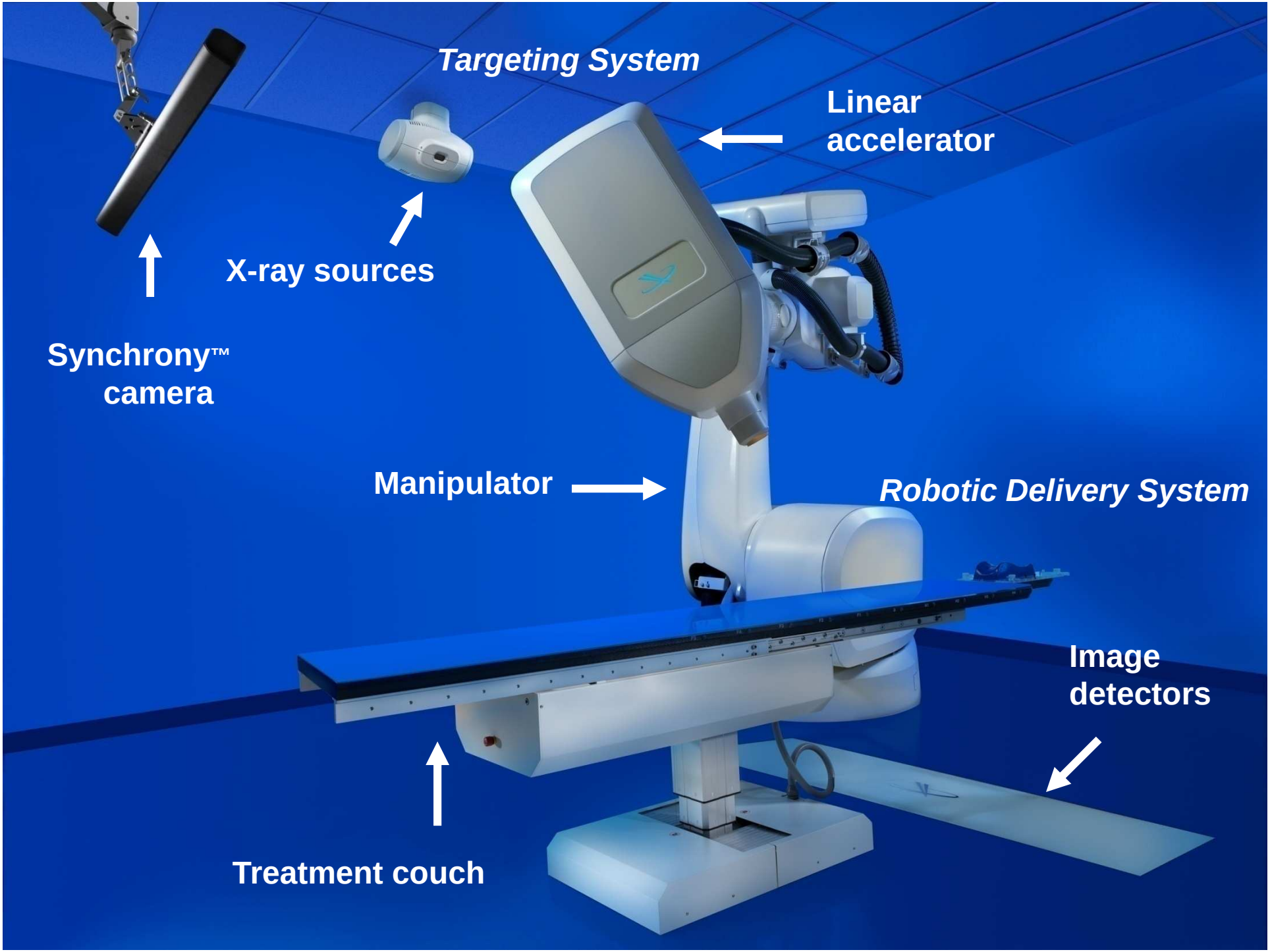








* Slide courtesy of Brian Kavanagh / University of Colorado


Targeting System
Linear accelerator
X-ray sources
Synchrony™ camera
Manipulator
Robotic Delivery System
Image detectors
Treatment couch

COLLIMATORS

- **Twelve Secondary Collimators**

  (5mm dia. to 60 mm dia.)

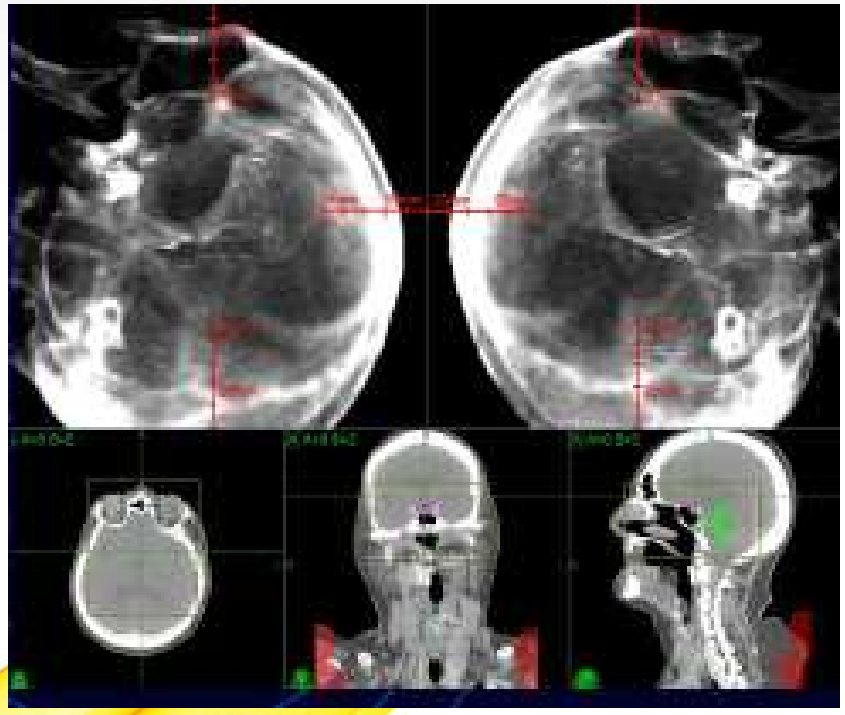
- **Variable Aperture collimator - Iris**

TRACKING SYSTEM

- **6D skull tracking system**
- **X-sight Spine tracking**
- **Fiducial tracking**
- **Synchrony Respiratory tracking**

6D SKULL TRACKING

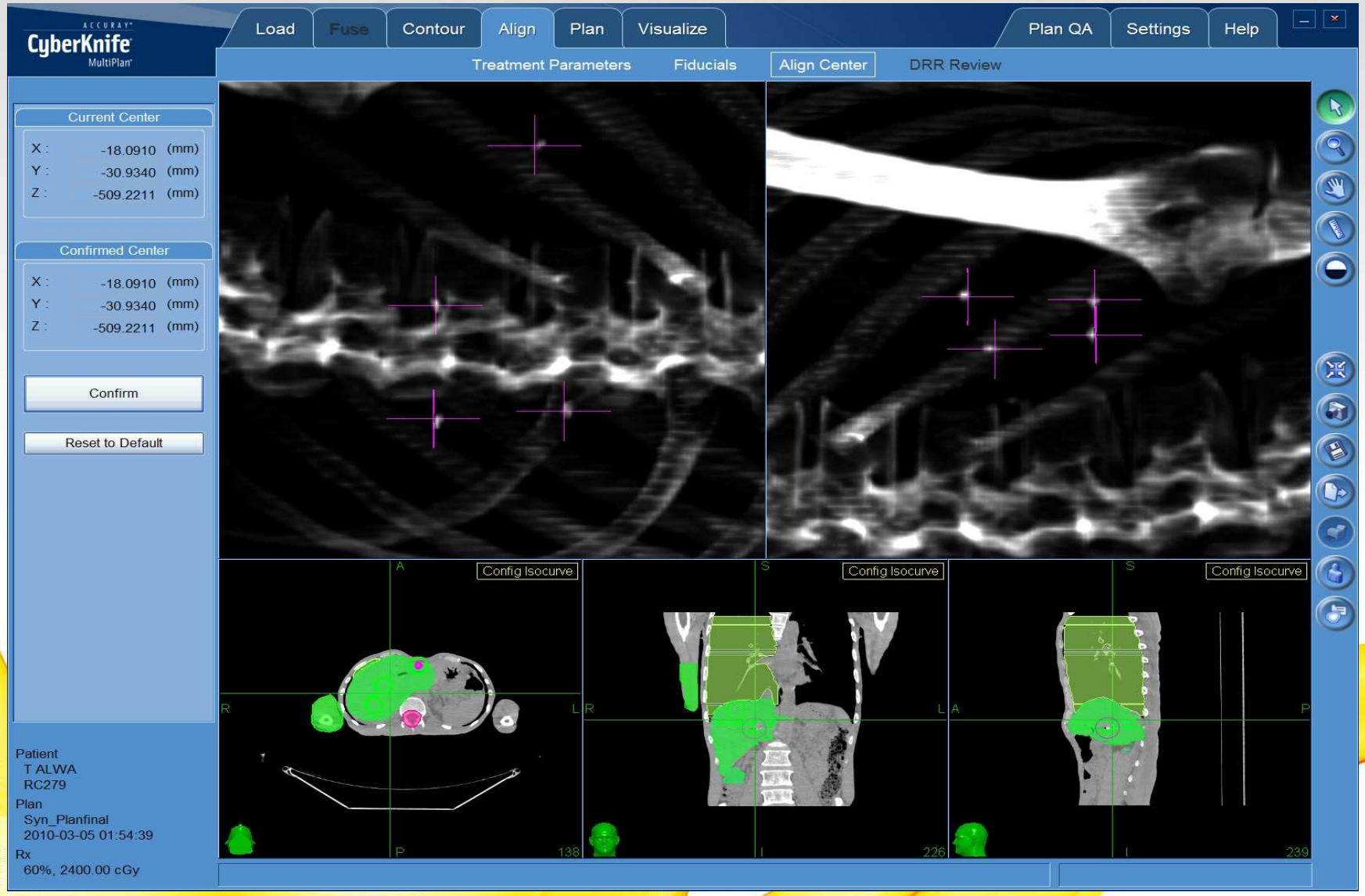
- **Used for cranial lesions down to C3**
- **Uses bony anatomy from DRRs as reference**
- **Position calculated in 6 degrees (Transverse and rotational)**
- **Fast and accurate (better than 0.5 mm accuracy)**



Fidicial Tracking System

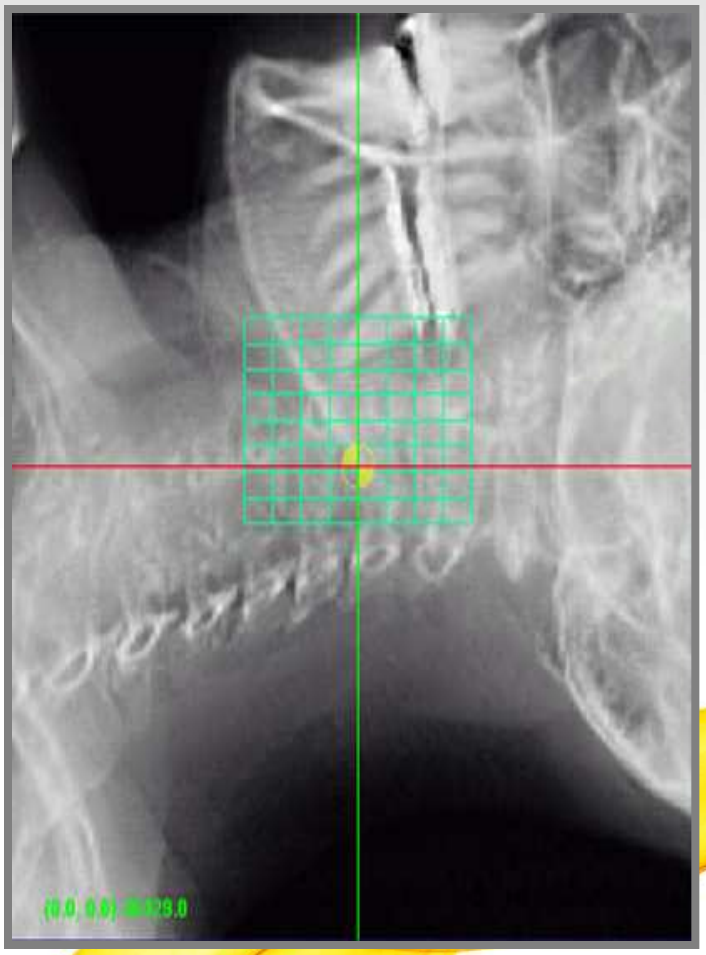
- Gold Seed fidicial :
  - Diameter : 0.7 to 1.2mm
  - Length : 3 mm to 6 mm
- Minimum one fidicial is need to track translation error
- Minimum three fidicial is need to track both translation and rotational error

Fidicial Tracking System

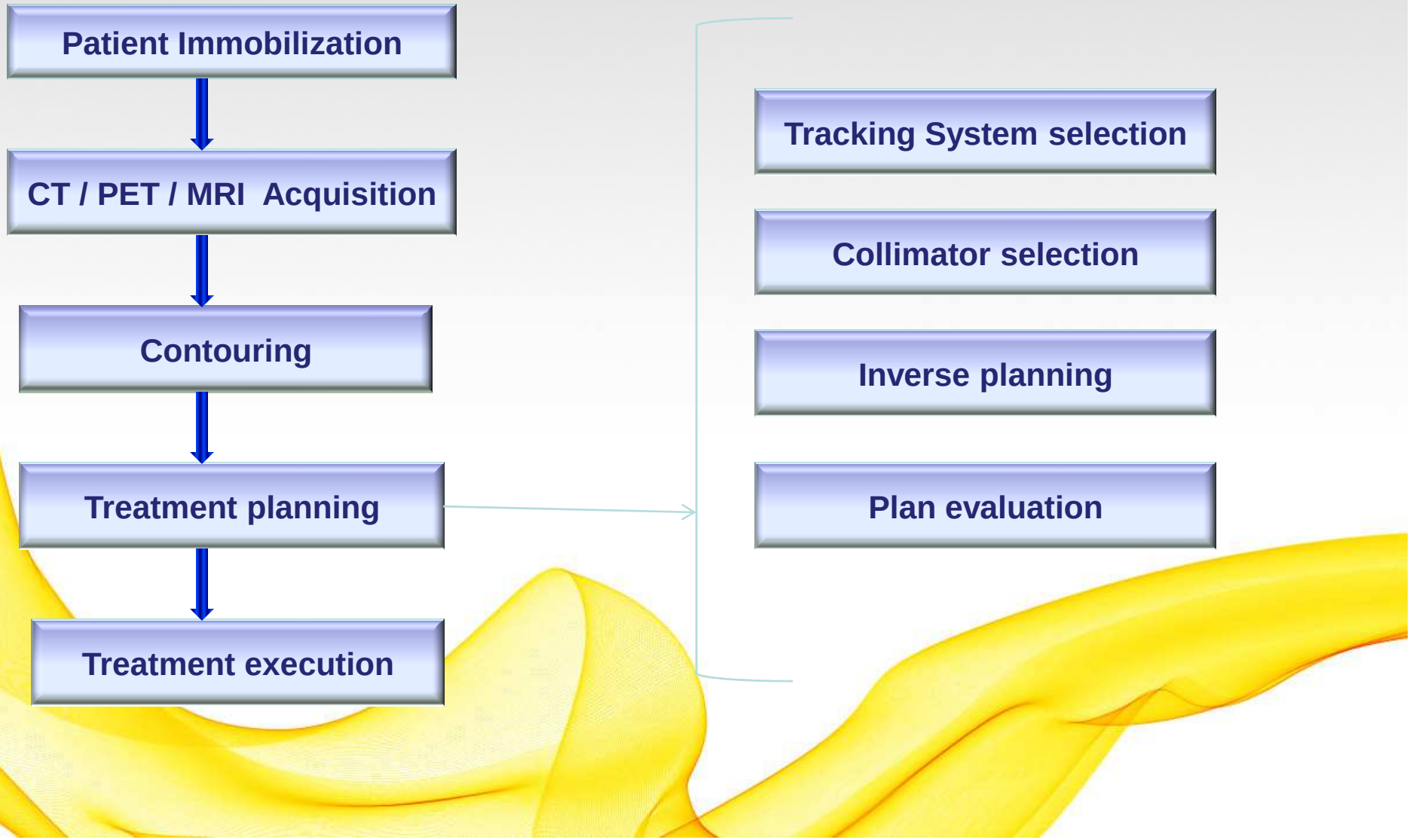


Xsight™ Spine Tracking System

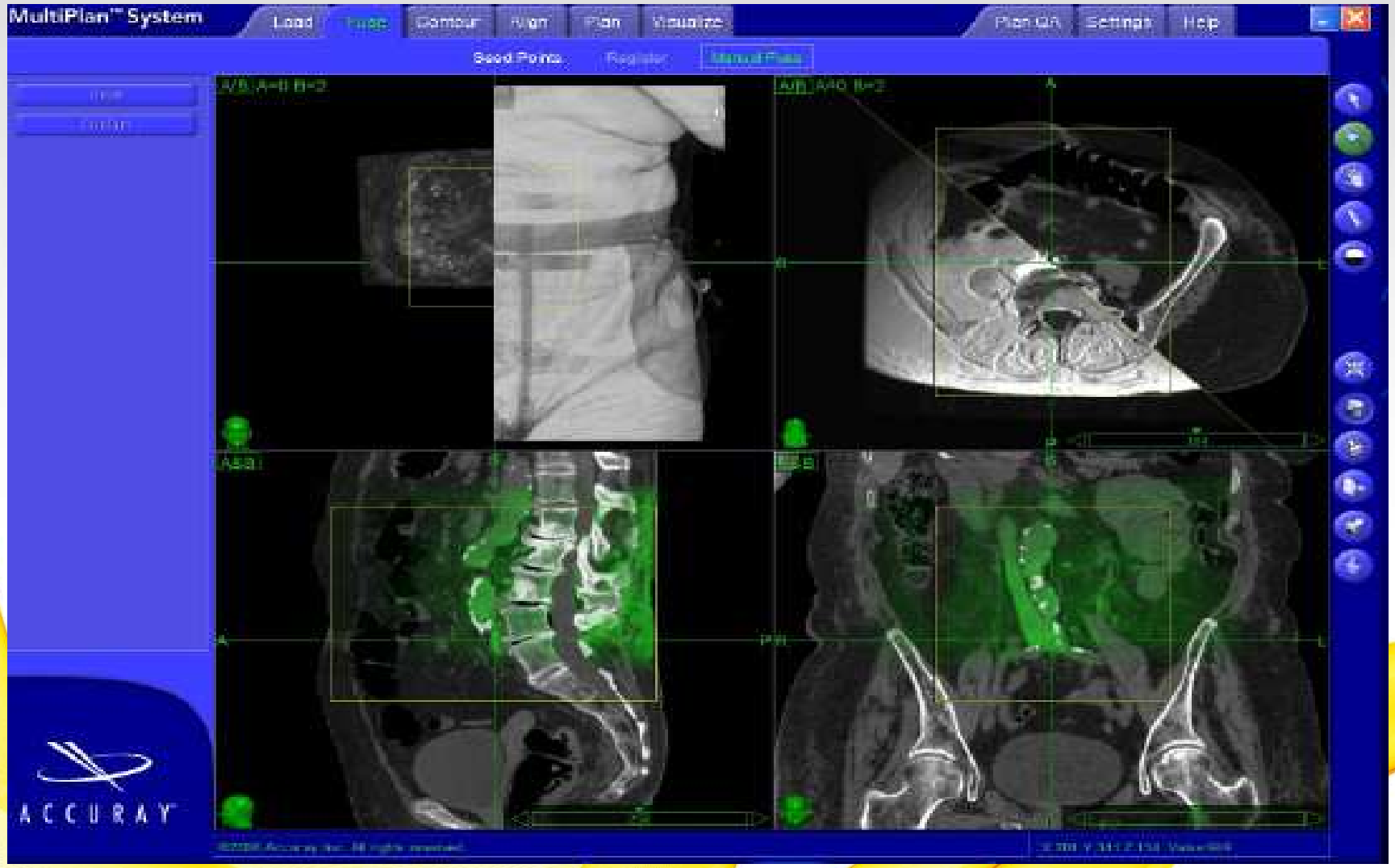
- Automatically locates and tracks tumors along the spine
- Eliminates the need for surgical implantation
- Utilizes the bony anatomy of the spine:
  - Cervical
  - Thoracic
  - Lumbar
  - Sacrum



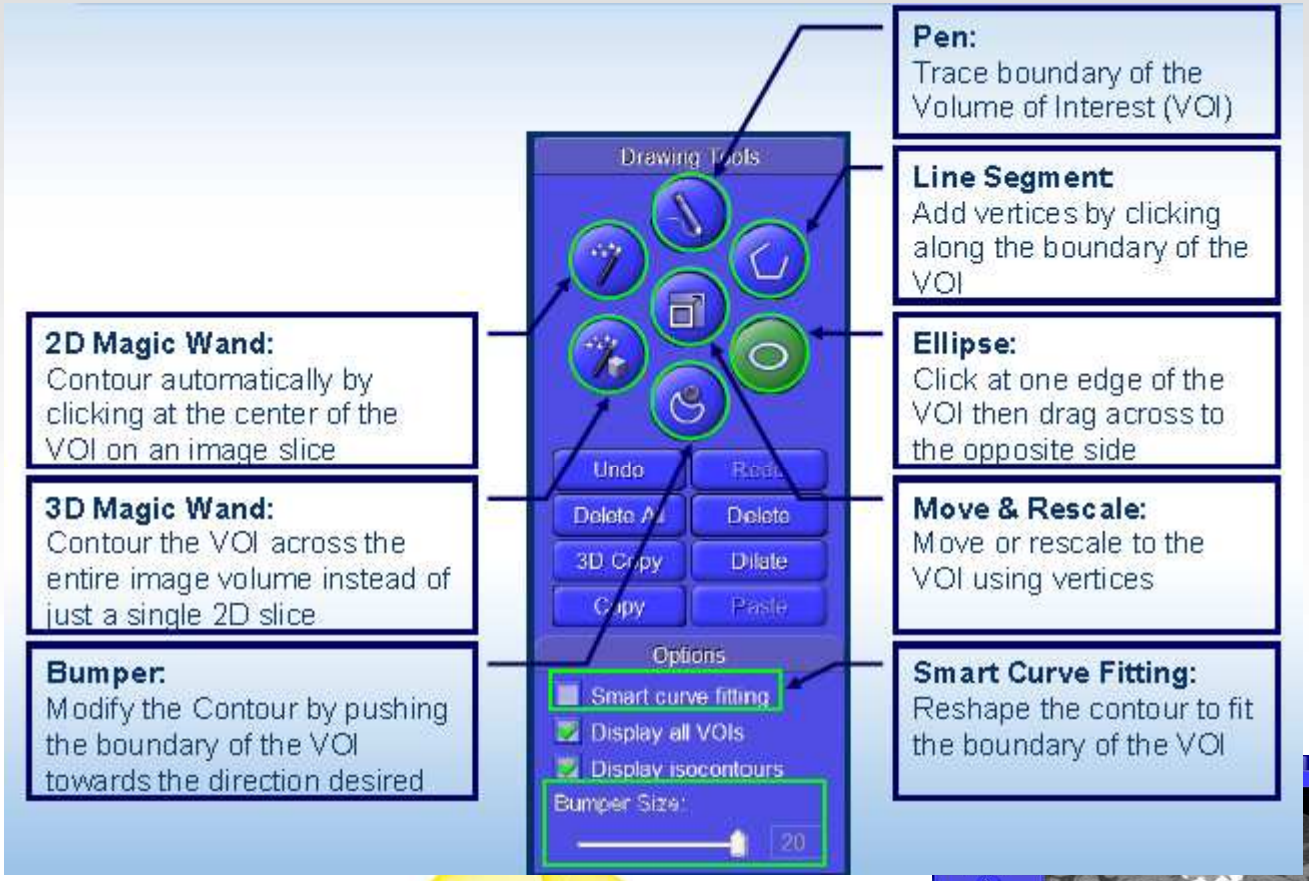
TREATMENT PLANNING PROCEDURE



Treatment Planning – Image fusion



Treatment Planning – Contouring



Pen:
Trace boundary of the Volume of Interest (VOI)

Line Segment
Add vertices by clicking along the boundary of the VOI

Ellipse:
Click at one edge of the VOI then drag across to the opposite side

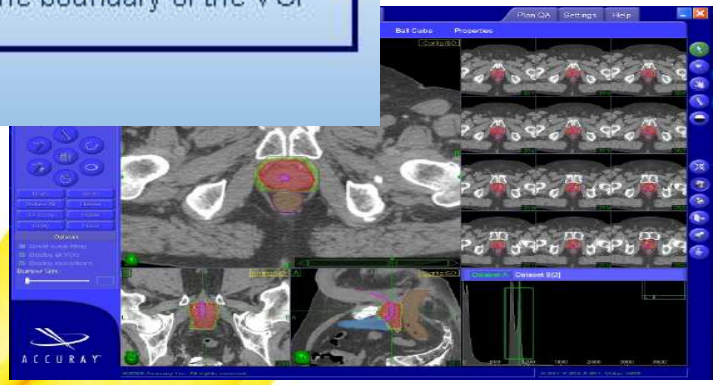
Move & Rescale:
Move or rescale to the VOI using vertices

Smart Curve Fitting:
Reshape the contour to fit the boundary of the VOI

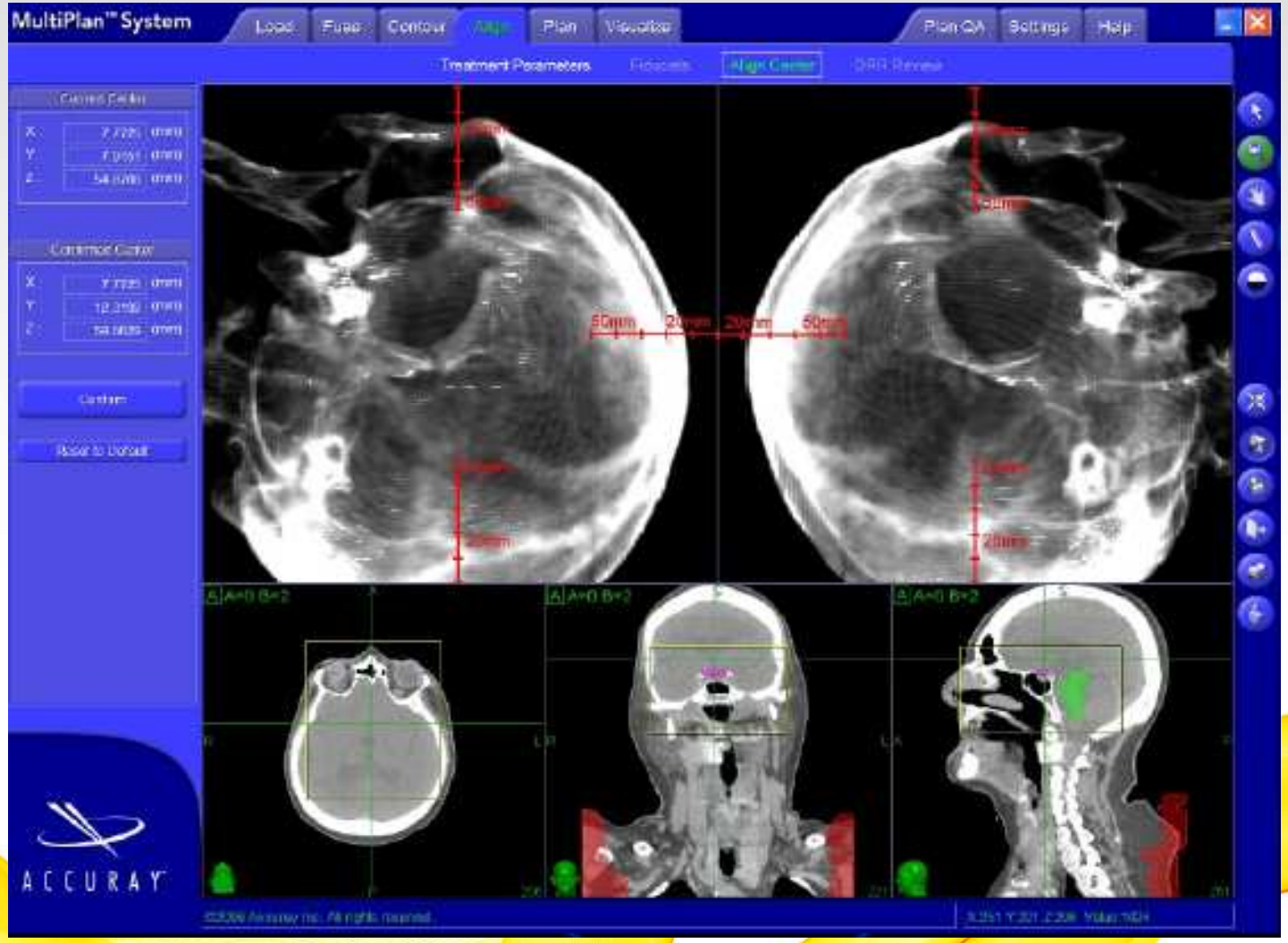
2D Magic Wand:
Contour automatically by clicking at the center of the VOI on an image slice

3D Magic Wand:
Contour the VOI across the entire image volume instead of just a single 2D slice

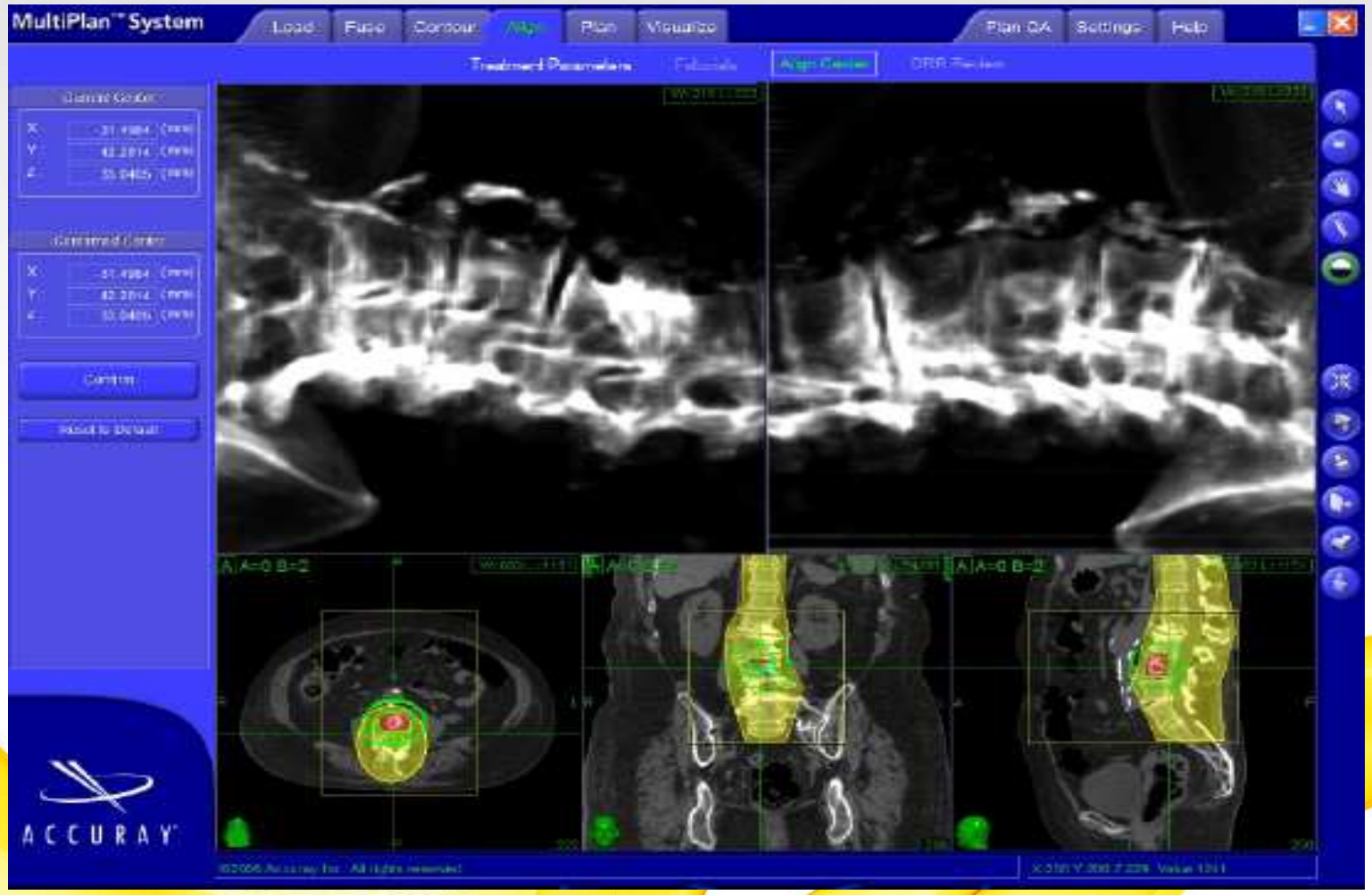
Bumper:
Modify the Contour by pushing the boundary of the VOI towards the direction desired



Treatment Planning – Alignment (6D Skull)



Treatment Planning – Alignment (Xsight Spine)



Treatment Planning – Alignment (Fidicial)

Treatment Process - Treatment planning parameter selection

- **Collimator size (40% to 60% target area)**
- **Optimization technique**
  - **Isocentric / isocentric conformal**
  - **Conformal**
  - **Simplex**
  - **Iterative**
- **Target and critical structure constraints**
- **Tuning and avoidance structures**
- **Minimum / maximum MU**

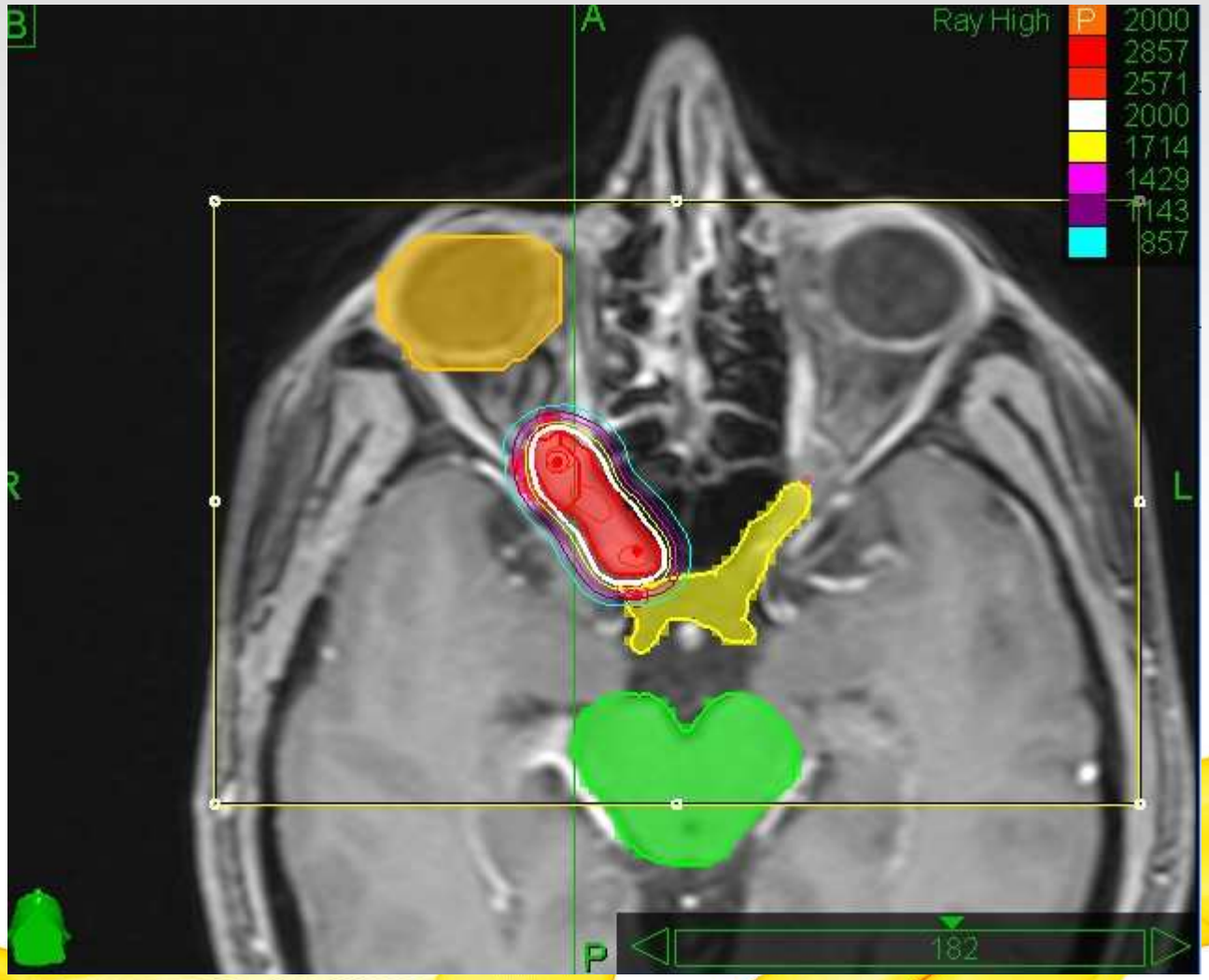
Treatment Process - Treatment execution

- **Final Plan Export to CK Control console**

On the TDS:

- DRRs generated from the plan CT
- Acquire an X-ray image
- Compare X-ray image position to DRR position
- Assess the couch corrections required to achieve patient alignment
- Make AutoCouch corrections as required

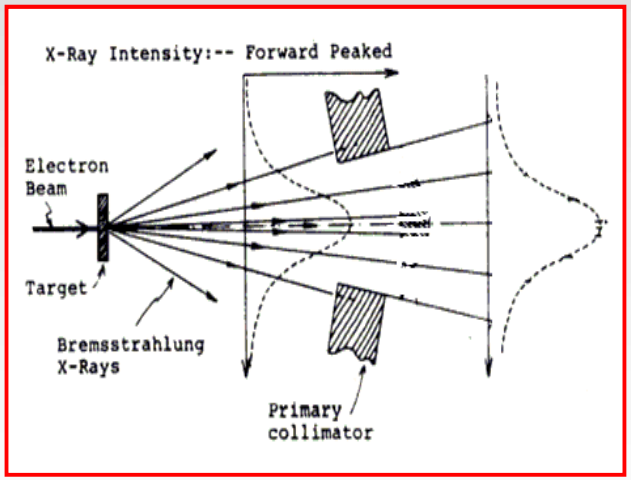
Planed at our site…..



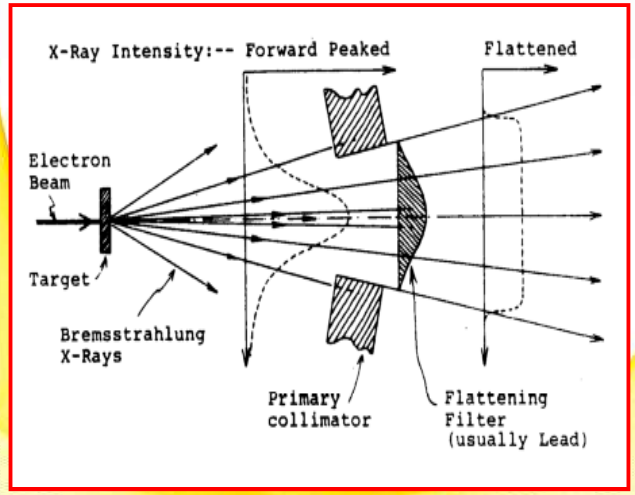
Optic nerve glioma

Flattening Filter Free Beam

Flattening Filter Free Beam



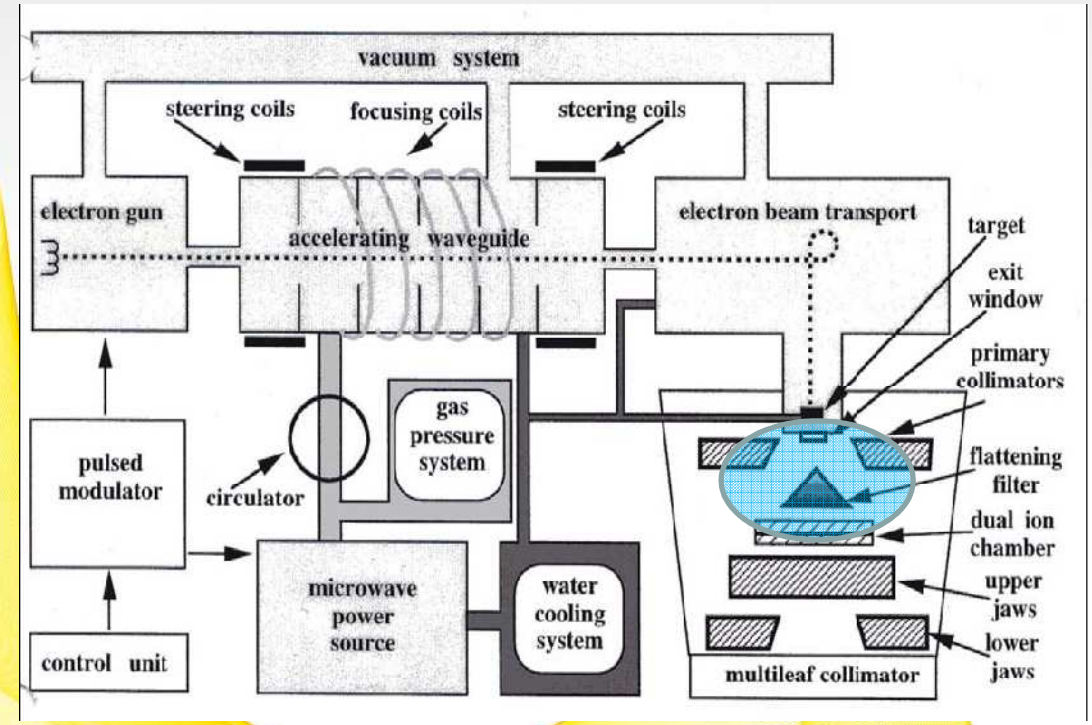
- Dose Rate High (~ 2400 MU/min)
- Reduced scatter , leaf transmission and radiation head leakage
- Reduced peripheral exposure

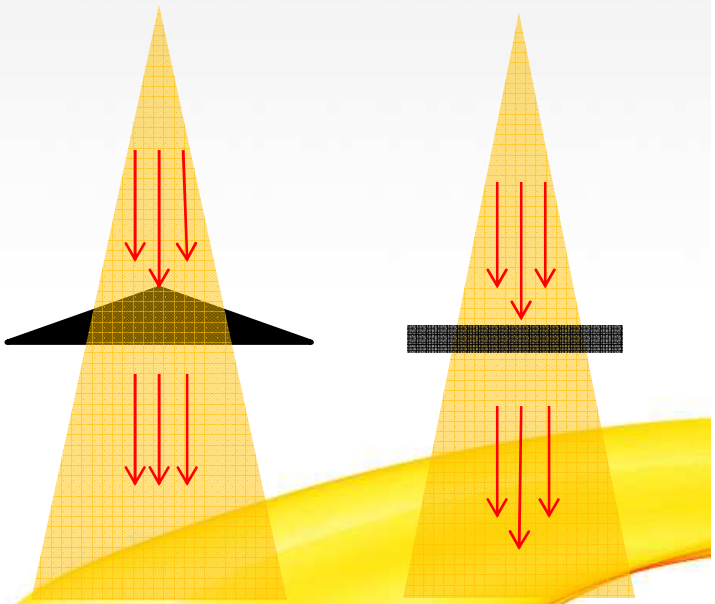


- **Without FF :** Forward peaked bremsstrahlung spectrum
- To compensate for this effect Flattening Filter (FF) has been introduced
- Due to this :
  - Dose rate substantially affected(~ 600MU/min)
  - A major source of head scatter

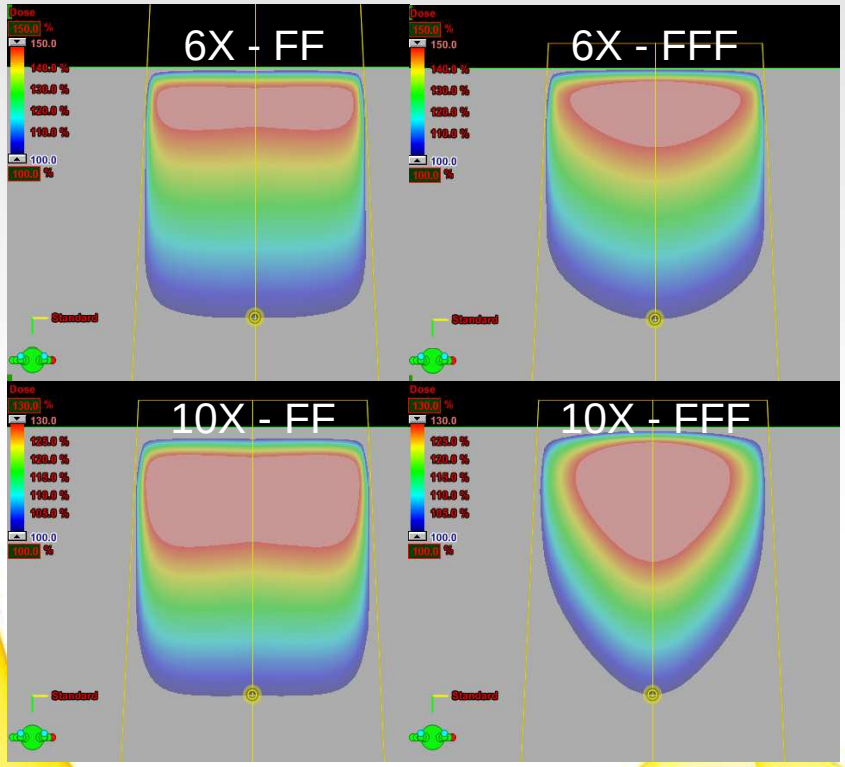
Flattening Filter Free Beam

Removal of the flattening filter from the LINAC Head..

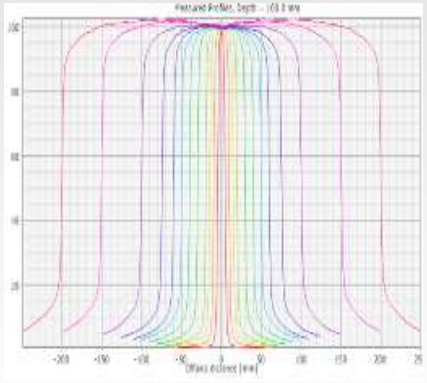




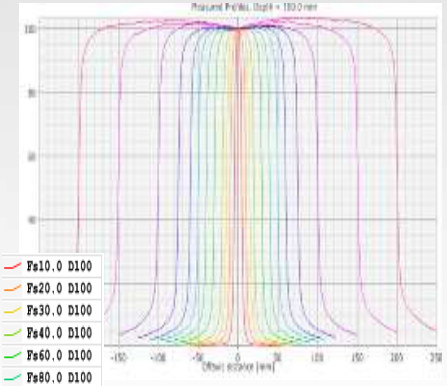
FFF BEAM PROFILE..

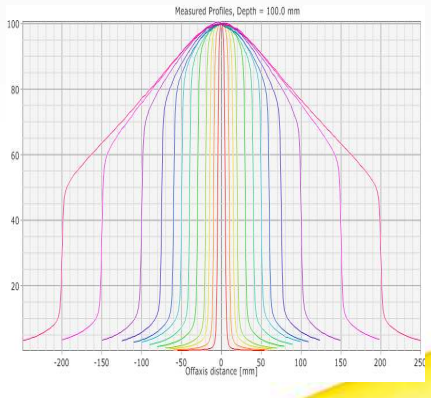


6X-FF

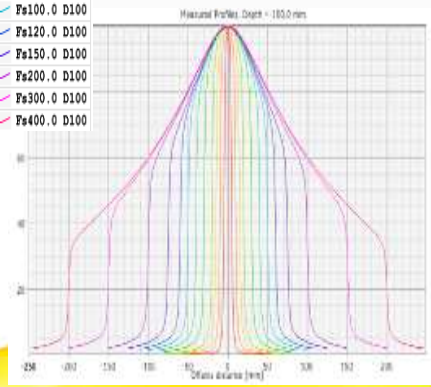


10X-FF





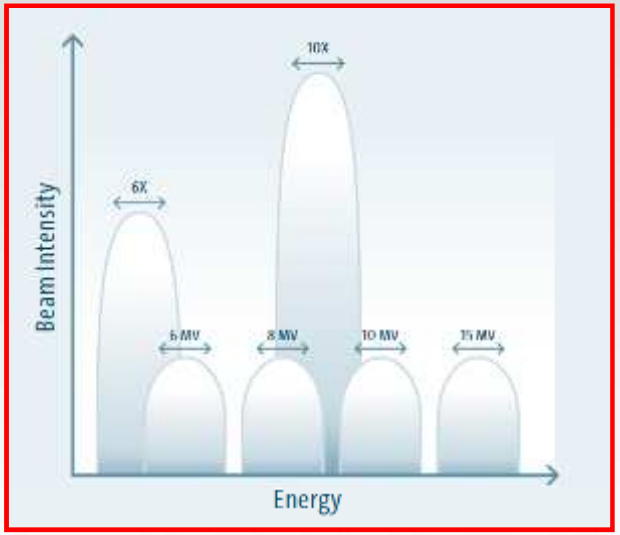
6X -FFF



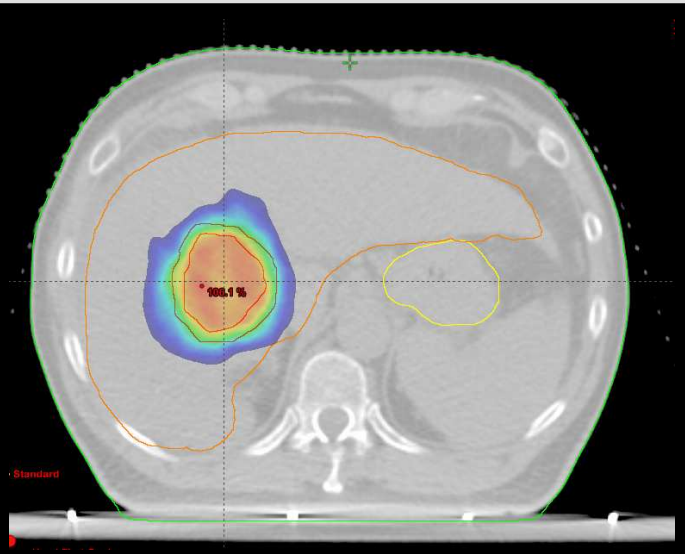
10X-FFF

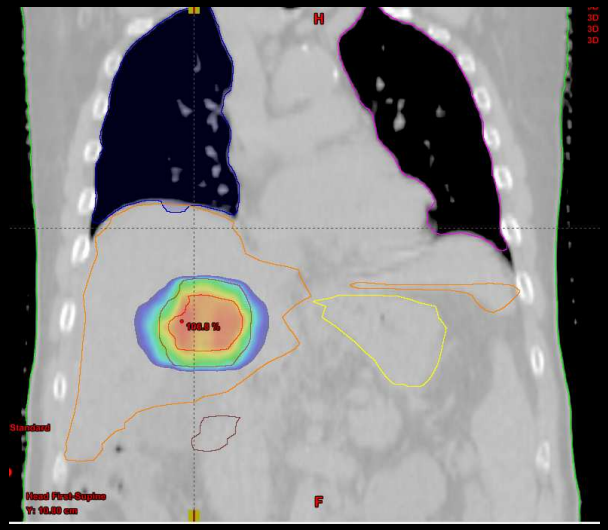
TRUE BEAM

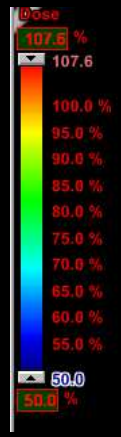
- Multi-Energy: 13 Carousel Positions available
- 4 Flattened Photon Energies: 6, 8, 10 & 15 MV
  - From low dose rates through 600 MU/min
- 2 High Intensity Mode Energies:
  6X FFF, 10X FFF (Flattening Filter Free, **2400 MU/min**)
- 8 electron energies: many foils, 22e (max)

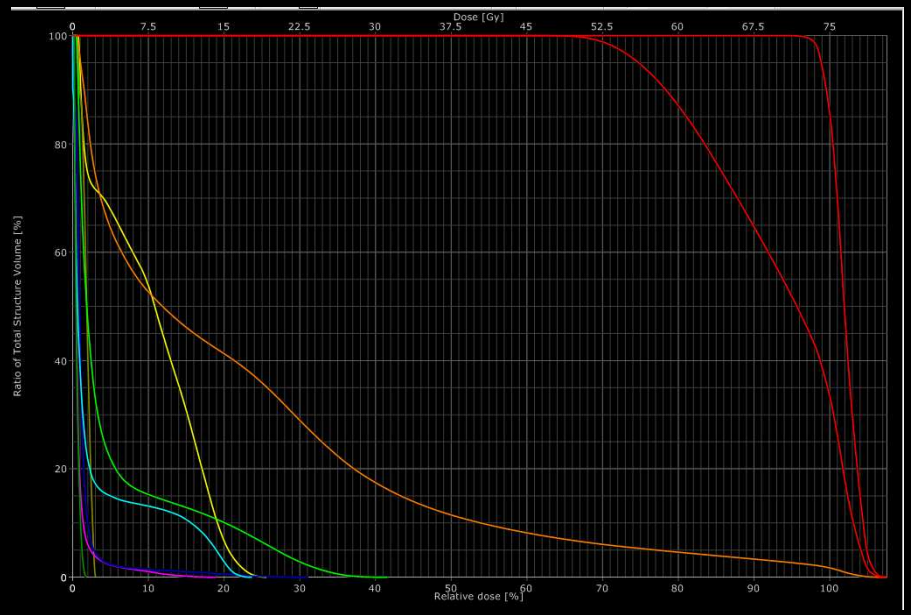


SBRT liver with TB: 25Gy x 3; 10FFF; DR 2400.







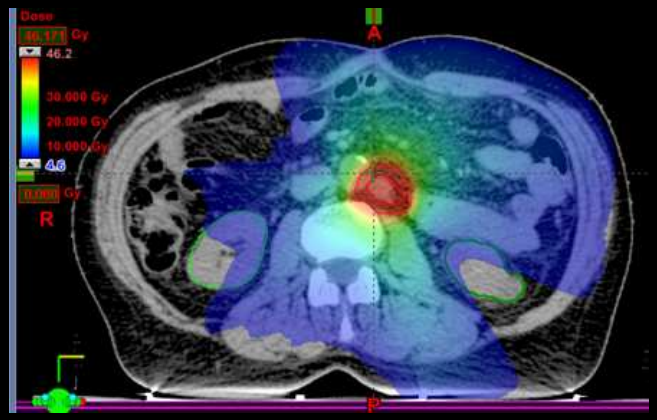


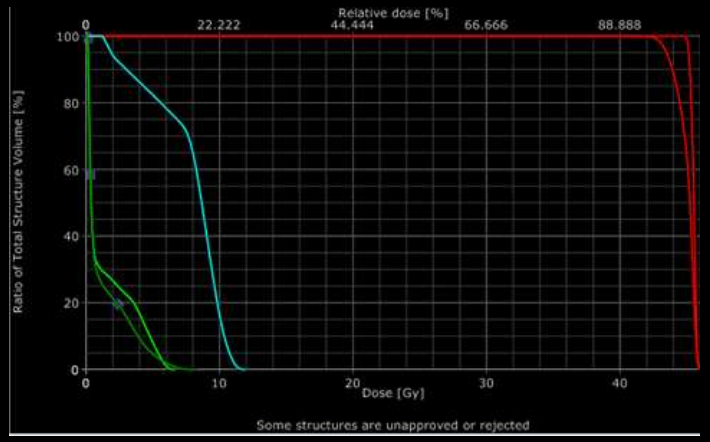
1 isocentre, 1 arc
Jaw tracking

MU: 5642
BOT: 137s

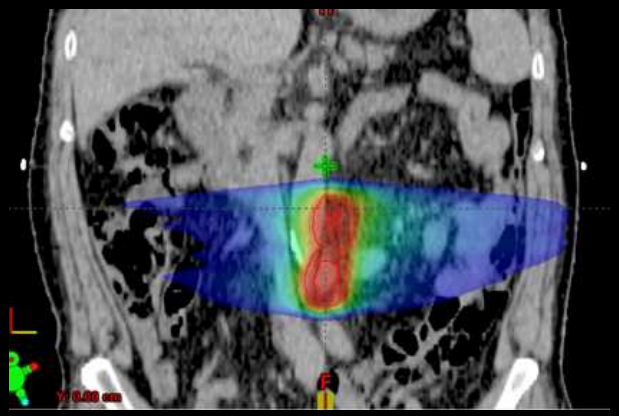
Spinal cord max dose = 17.3 Gy
Right kidney mean dose = 3.9 Gy
Liver mean dose = 15.7 Gy
Stomach mean dose = 19.3 Gy

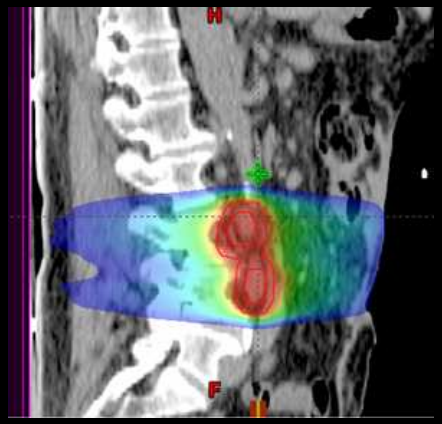
Abdominal Mets SBRT. 10XFFF, DR:2400. 6x7.5 Gy





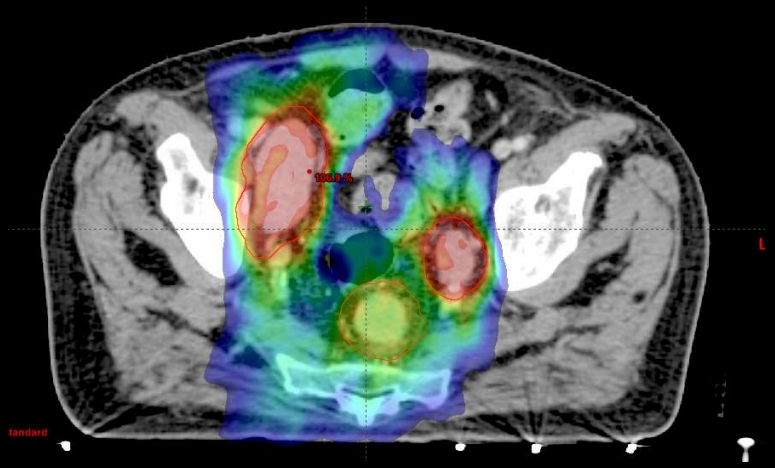
1 isoc, 1 arcs
Jaws tracking
MU: 1697
BOT: 60 sec

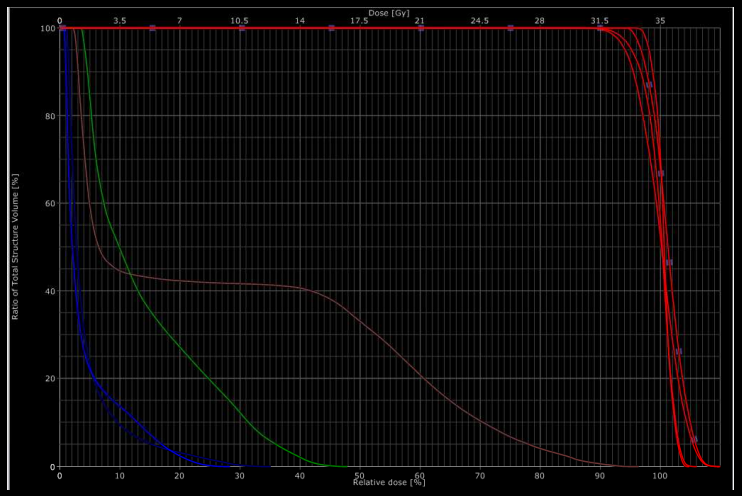




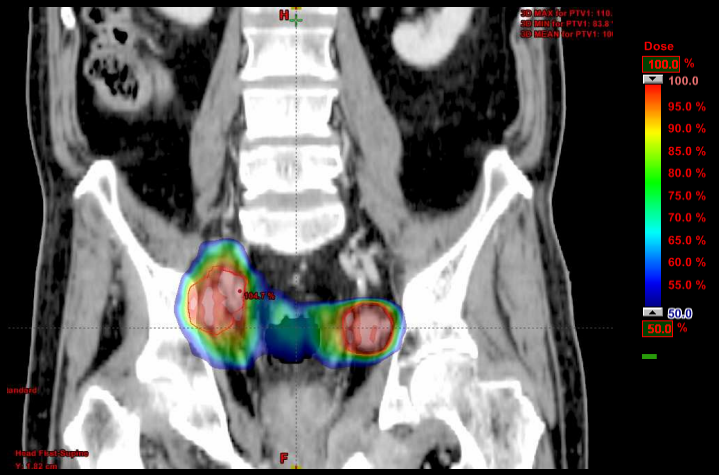
Kidneys mean dose = 1.5 Gy
Spine: max dose = 7.5 Gy

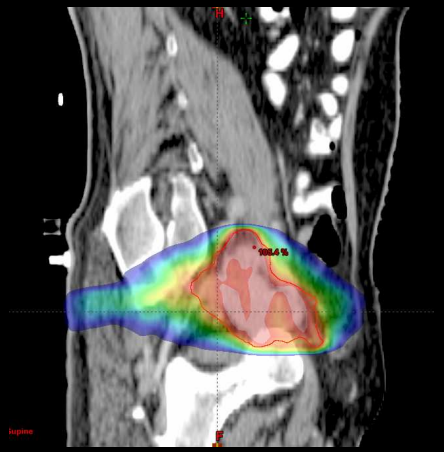
SBRT: 3.5Gyx10;6FFF;DR 1200.





Rectum mean dose = 9.9 Gy
Femoral heads mean dose = 1.6 Gy





1 isoc, 1 arcs
Jaws tracking
MU: 1065
BOT: 66 s

THANKS….