Physical Parameters in External Beam Photon Therapy – Simulation, Planning, Verification, Delivery

Rajesh A. Kinhikar

Professor & Head,

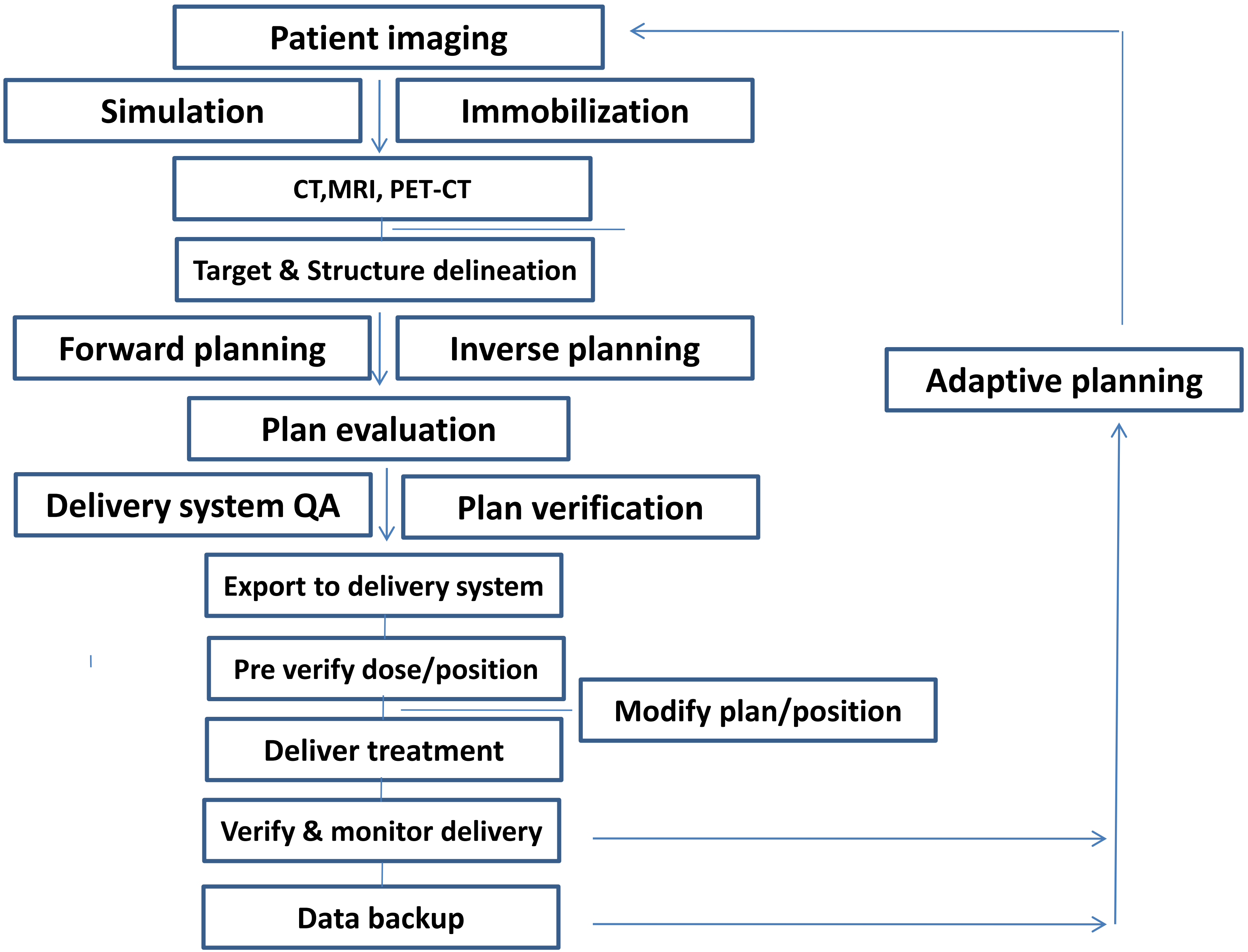
Department of Medical Physics

Tata Memorial Centre, Mumbai.

rkinhikar@gmail.com

Outline

- **Physical Parameters in External Beam Photon Therapy**
  - **Immobilization**
  - **Simulation**
  - **Planning & Evaluation**
  - **Pre-treatment Verification (Imaging, QA etc)**
  - **Delivery**
- **Summary**



Patient imaging
Simulation
Immobilization
CT,MRI, PET-CT
Target & Structure delineation
Forward planning
Inverse planning
Adaptive planning
Plan evaluation
Delivery system QA
Plan verification
Export to delivery system
Pre verify dose/position
Modify plan/position
Deliver treatment
Verify & monitor delivery
Data backup

IMMOBILIZATION & BEAM DEFINING DEVICES

Rubber Traction

Rubber traction is used to extend the arms towards feet so that primary beam irradiate head and neck tumour directly without giving unwanted dose to the shoulders.

Plaster Of Paris Mould **$(CaSO4)_2 H_2O$**

- Used for Portal demarcation & immobilization in head & neck cancers

Materials required:

- POP Bandages
- Aluminum wire
- Base plate
- Rubber traction
- Head rest
- Vaseline

Plaster of Paris Mould

Maintenance & Repair

- It should be handled carefully & stored properly during treatment. Chances of becoming loose after prolonged use.

Advantages

- Materials are easily available.
- Relatively inexpensive.
- Can be easily modified.

Disadvantages

- Not very rigidly immobilized.
- Cannot be reused.
- Gets damaged very soon & requires frequent reinforcement

ACRYLIC MOULD /COBEX CAST

Materials

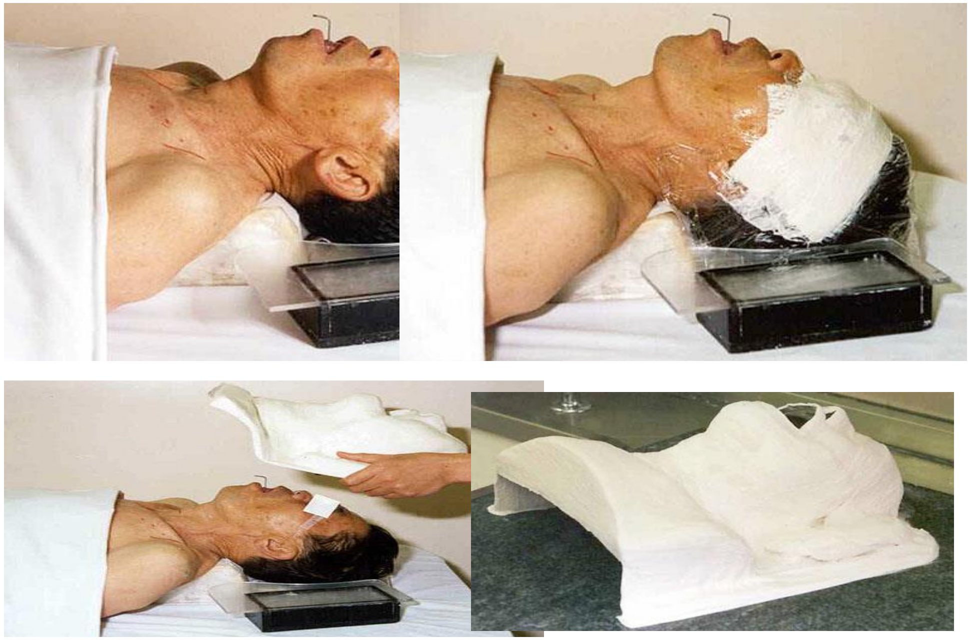
- POP bandages
- Self curing acrylic resin (cold cure)
- Monomer (liquid), Polymer (powder)
- Dental Stone, Vaseline
- Base plate, Water
- Head rest, Rubber traction

It can be made from a self polymerizing acrylic resin which comes in two parts

(a) Liquid (b) Powder.

Use

- Immobilization & beam direction in head & neck region
- Carrier for surface mould brachytherapy.



24 Hr

Maintenance & Repair **(ACRYLIC MOULD /COBEX CAST)**

- Relatively delicate
- Fracture can be fixed using self curing resin paste

Advantages

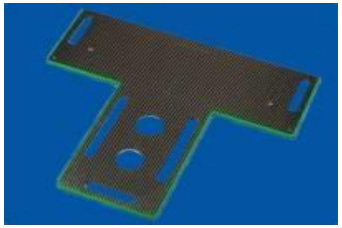
- Effective fixation
- Close conformity between mould & body surface
- Portals can be marked on the mould
- Windows may be cut
- Wax bolus can be fixed
- Can be used for CT scan / MRI without causing any distortion of images

Disadvantages

- Difficult & time consuming to make
- Expensive
- Cannot be reused

THERMOPLASTIC
(Cellulose acetate / Polyvinyl Chloride).

- ❖ Heat sensitive material
- ❖ available in the form of sheets in different size, shape & thickness.
- ❖ Heated to a temperature of 70 degree Celsius ,
- ❖ it becomes soft and elastic.
- ❖ When spread on a surface & allowed to cool it takes the shape of the surface & retains it.



Materials

- Thermoplastic sheets (orfit)
- Immobilization and positioning devices.
- Water bath with thermostat

THERMOPLASTIC (cellulose acetate / polyvinyl chloride)

Advantages

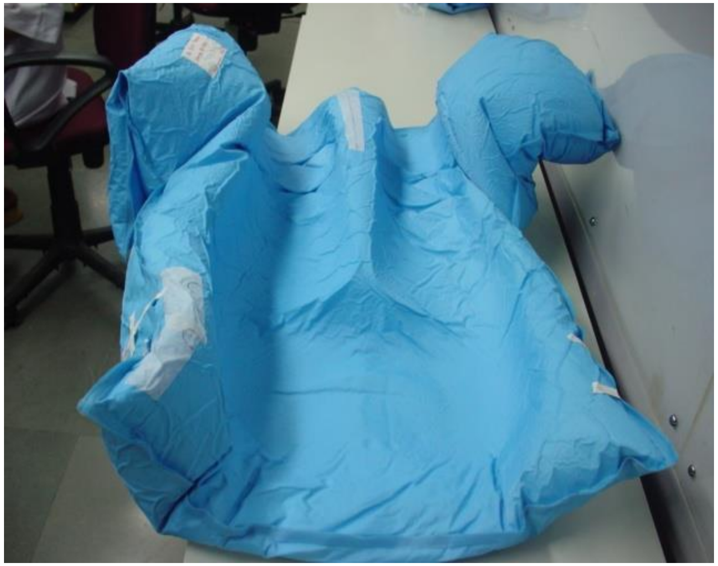
- Suitable for all sites.
- Close conformity with body surface
- Easy to make & less time consuming
- Portals can be marked on the surface
- Windows can be cut
- Wax bolus can be fixed
- Can be used for CT / MRI without distortion of image
- Very effective fixation
- Can be modified easily
- Sturdy & no damage in routine use
- Reusable

- Disadvantages – disposal (environmental!!!)

VACUUM IMMOBILIZATION CUSHION/VACLOC

Components

- Vacuum cushions of appropriate size
- Vacuum pump with pressure guage



VACUUM IMMOBILIZATION CUSHION/VACLOC

- Shell of tough urethane plastic material filled with tiny polystyrene beads.
- When air is removed from the cushion by a vacuum pump the micro spheres are pulled together tightly & become rigid.
- It retains exact shape of any object in contact .
- When used along with a sterotactic body frame (SBF), high reproducibility of patient position is achieved.

Advantages

- Easy to use & requires very little time to prepare
- Accurate Immobilization
- Comfortable for patient
- Can be reused

Disadvantages

- Shape may change with handling & use
- Storage
- Expensive

IMMOBILIZATION MASK FOR SRT

- Stereotactic conformal radiotherapy is a specialized form of high
  precision radiotherapy which delivers highly focused conformal
  radiation beam to a perfectly immobilized target
  .
- Target volume is very small and the margin are tight.
- Important that immobilization is perfect.


Components

- Special thermoplastic sheets
- Clips & spacers , Klin-foil
- U frame, Couch mounts
- Water bath

Maintenance

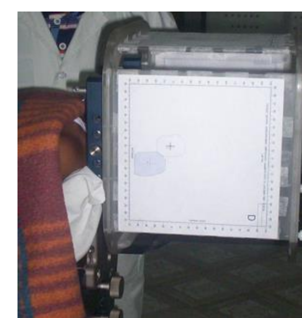
- Generally no maintenance is required

Advantages

- Very rigid, Accurate immobilization, Relocatable.

Disadvantages

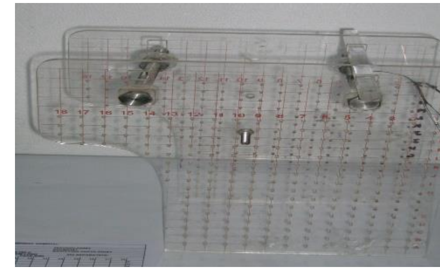
- Cannot be reused, Expensive

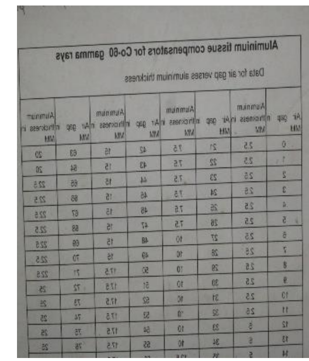


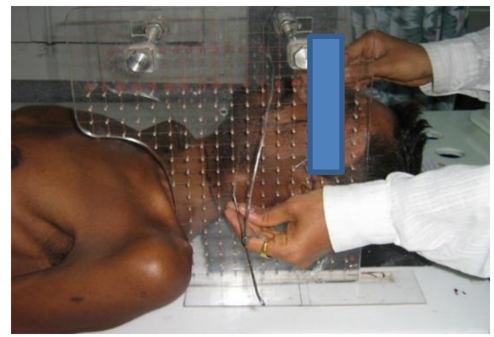
BEAM MODIFYING DEVICES

TISSUE COMPENSATORS

- It is a beam modification device which compensates for missing tissues so that the standard depth dose data can be used for sites like head and neck, thorax etc.

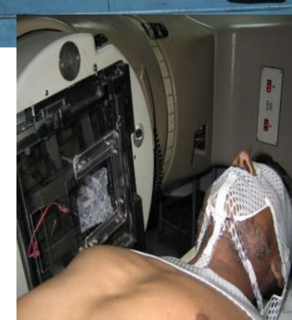






Components

- Special jig for measurement
- Recording sheet
- Base plate for fixing mould
- Head rest
- Compensator material [Al/Pb]
- Thin perpex sheet for mounting
- Fevicol

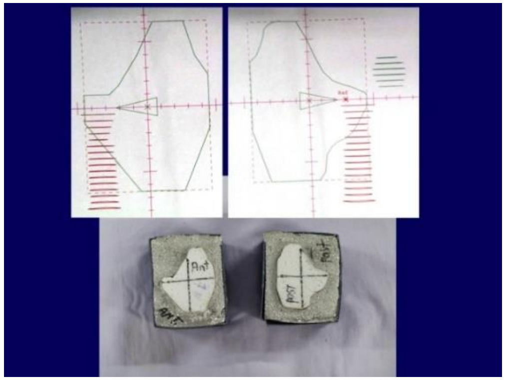


CONFORMAL BLOCKS (photon & Electron

- Used for irregularly shaped photon & electron radiation fields

Materials

- Simulator radiograph with
  target volume
- Immobilization device
- Thermocole / Styrofoam sheet
- Styrofoam cutting device
- Cerrobend material [oestalloy, Density 9.4 gm/cc], Melting point 70 deg celcius
- Composition as Bismuth 50%, Lead 25%, Cadmium 13% & Tin 12%
- Cardboard box
- Perspex tray for fixing



BOLUS (Wax or paraffin etc) variable thickness

Imaging

IMAGING MODALITIES

- No single imaging modality produce all the information needed for the accurate identification and delineation of the target volume and critical organs.
- Various imaging modalities used are :
  - Computed Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
  - Positron Emission Tomography (PET)-CT

Computed Tomography (CT)

Advantages of CT:

- Gives quantitative data in form of CT no. (electron density) to account for tissue heterogeneities while computing dose distribution.
- Gives detailed information of bony structures
- Potential for rapid scanning
- 4 -D imaging can be done.
- Widely available;

CT SIMULATOR

- Images are acquired on a dedicated CT machine called CT simulator with following features
  - A large bore (75-85cm) to accommodate various treatment positions along with treatment accessories.
  - A flat couch insert to simulate treatment machine couch.
  - A laser system consisting of
    - Inner laser
    - External moving laser to position patients for imaging & for marking
    - A graphic work station

MRI

- Advantages of MRI
  - No radiation
  - Unparalleled soft tissue delineation
  - scans directly in axial, sagittal, coronal or oblique planes
  - Vascular imaging with contrast agents

PET scan (functional imaging)

To inspect blood flow, oxygen intake, or the metabolism of organs and tissues.
To identify the problems at the cellular level, giving the best view of complex systemic diseases.

PET scans are most commonly used to detect:
1. Cancer
2. Heart problems
3. Brain disorders, including problems with the CNS .

PET-PRINCIPLE

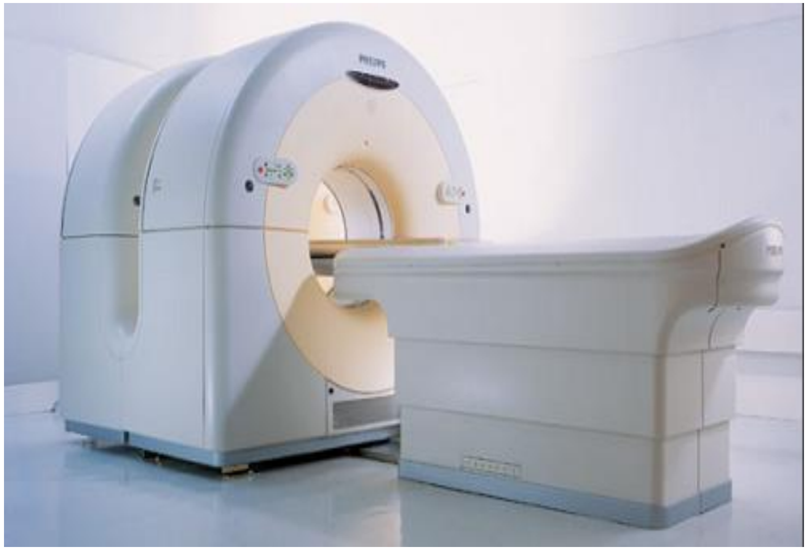
- Positron emitting radionuclide, produced by bombardment of stable nuclide with proton from a cyclotron, are attached to biological markers
- Most commonly used biological marker in cancer diagnosis is - ^{18}F radionuclide attached to 2-fluoro-2 deoxy - D-glucose (FDG).
- Cancer cells metabolize radiolabelled glucose at much higher rate than normal cells.
- PET detects photons liberated at 180° by annihilation reaction of positron with electron

- Simultaneous detection of this pair and subsequent mapping of the event of origin allows spatial localization
- The detectors / scintillators (BGO) are arranged in an circular array around the patient & convert γ - energy into visible photons detected by PMTs
- Disadv. of PET
  - poor resolution
  - can not pinpoint exact size & location of tumors to the precision required for optimal diagnosis & treatment planning
  - Separate PET & CT images are difficult to fuse

PET/CT

- Recently introduced PET/CT machines, integrating PET & CT technologies , enables the collection of both anatomical & biological information simultaneously

- ADV. of PET/CT:
  - Earlier diagnosis of tumour
  - Precise localization
  - Accurate staging
  - Precise treatment
  - Monitoring of response to treatment



ULTRASOUND

- Ultrasound is safe and painless.
- It produces pictures of the inside of the body using sound waves.
- Ultrasound imaging is also called ultrasound scanning or sonography.
-
- It uses a small probe called a transducer and gel placed directly on the skin.
- High-frequency sound waves travel from the probe through the gel into the body.
- The probe collects the sounds that bounce back.
- A computer uses those sound waves to create an image.
- do not use radiation (as used in X-Rays).
- Because images are captured in real-time, they can show the structure and movement of the body's internal organs.
- They can also show blood flowing through blood vessels.
- Ultrasound imaging is a noninvasive medical test that helps physicians diagnose and treat medical conditions.
- Conventional ultrasound displays the images in thin, flat sections of the body.
- Advancements in ultrasound technology include three-dimensional (3-D) ultrasound that formats the sound wave data into 3-D images.

Risks	Potential impact	Solutions
Incorrect identification of patient	High	ID check open questions, eliciting an active response as a minimum 3 points of ID Photo ID
Incorrect positioning of reference points and guides	High	Competency certification Appropriate education Independent checking
Defining wrong volume	High	
Incorrect margin applied around tumour volume	High	
Incorrect contouring of organs at risk	High	
Incorrect image fusion	Medium	
Light fields and cross-hairs could be misaligned	Medium	Equipment quality assurance Quality control checks with protocol for sign-off procedures
Inability to identify the isocentre consistently	High	
Poor image quality	Medium	
Incorrect imaging protocol	Medium	Planning protocol checklist Independent checks Signature protocols
Incorrect area imaged	Medium	
Wrong side/site imaged	High	
Altered patient position	High	
Incorrect orientation information	High	

Before simulation

- Ensure safety (identity , rule out pregnancy)
- Fitness for simulation
- Coaching and biofeedback
- Ensure availability of materials needed

Things to remember at Simulation

- Proper alignment and setup
- Bad immobilization and alignment not likely to be compensated for by fancy planning and delivery
- Reproducible organ filling protocols
- Organ Motion

Imaging format..DICOM

- Treatment planning systems (TPSs) are used to generate beam shapes and dose distributions
- TPS is interfaced to imaging modality & treatment delivery unit.
- For this interfacing all systems should be DICOM compatible
- DICOM stands for “Digital Imaging and Communications in Medicine”.
- DICOM & DICOM-RT are data exchange interface applications that support electronic transfer, print & storage of images, images related data & RT related data b/w DICOM compliant systems.

RELATIVE EFFICACIES

Table 1. Immobilization Capabilities

Site	*Technique*	*Treatment to Treatment*	*Simulation to Treatment*	*Alignment*
Pelvis/abdomen	Alpha-Cradle or thermoplastic casts	3-4 mm		Laser
	Unimmobilized	6-8 mm	6 mm	Laser
Breast	Alpha-Cradle or vacuum bead bags	3 mm		Light field
Thorax	Unimmobilized	4 mm	6 mm	Laser
Head/neck	Face masks w/neck	2.5-4 mm		Laser
	Mechanical	3 mm	2.5 mm	Laser
	Bite block	4 mm	6 mm	Laser
Intracranial	Unimmobilized	3 mm	5 mm	Laser
	Face mask w/neck	2.0-2.5 mm		Laser
	Cranial fixation (stereotactic)	< 1.0 mm		Mechanical
	Noninvasive (stereotactic)	1.0-1.5 mm		Mechanical

Immobilizing and Positioning Patients for Radiotherapy

Lynn J. Verhey

Seminars in Radiation Oncology, Vol 5, No 2 (April), 1995: pp 100-114

Sources of error

- Mechanical – Laser misalignment , couch sag , poorly fitting components of immobilisation system
- Patient related – limited mobility , movement of skin r
- Human error

Table 2. Limitations of Positioning Methods

Method	*Accuracy Limit*
Laser alignment using skin marks	2.0-2.5 mm
Radiographic alignment using anatomy	1.0-2.0 mm
Radiographic alignment using point markers	<1.0 mm
Mechanical positioning of indexed patient	<0.25 mm
Visual image alignment	~1.0 mm

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Organ motion

- Significant issue
- Geographical miss Vs large margins
- Especially significant in thoracic and abdomino-pelvic radiotherapy
  - Lung
  - Liver
  - Prostate
- **HYPOFRACTIONATED RADIOTHERAPY – MAGNIFIES ERRORS**

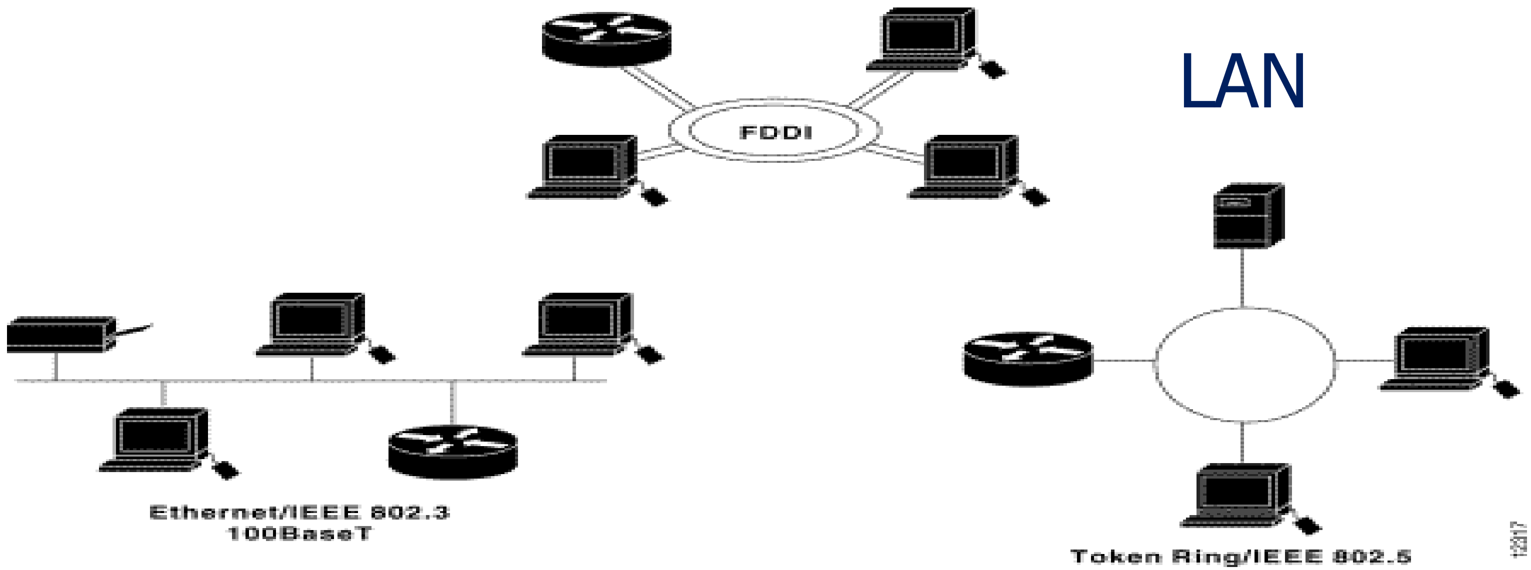
Technique	Commercial devices	Details of technique	Advantages	Disadvantages
Breath hold	Feedback-guided breath-hold treatment (FGBHTx), Elekta ABC	Beam delivery occurs during patient breath holds up to 15 s using a feedback device	Highly accurate	Requires good respiratory function, compliant patient, ability to breath hold, requires regular reproducible breathing
Respiratory gating	Varian RPM	Beam delivery occurs when tumor comes to a gated position based on external surrogate marker	Compatible with patients with poor lung function	Requires regular reproducible breathing, less efficient, reliance on external surrogate for tumor position
Free breathing (motion encompassing methods)	NA	Target volume encompass the entire extent of tumor motion	Compatible in patients with poor lung function; inexpensive	Increased volume of normal tissue irradiated

Networking

Basic Network Theory

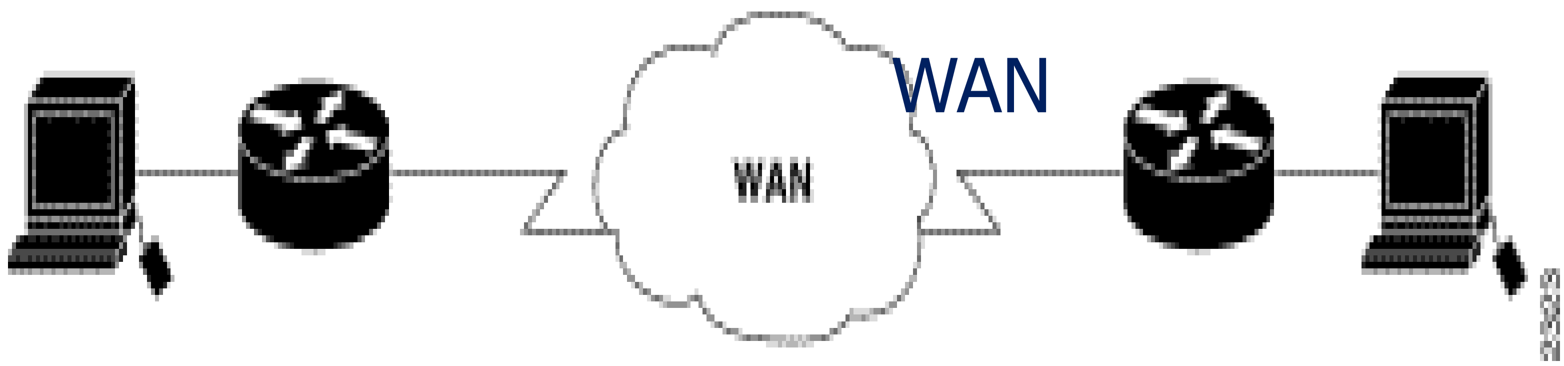
I) Local Area Network (LAN)

LAN



II) Wide Area Network (WAN)

WAN



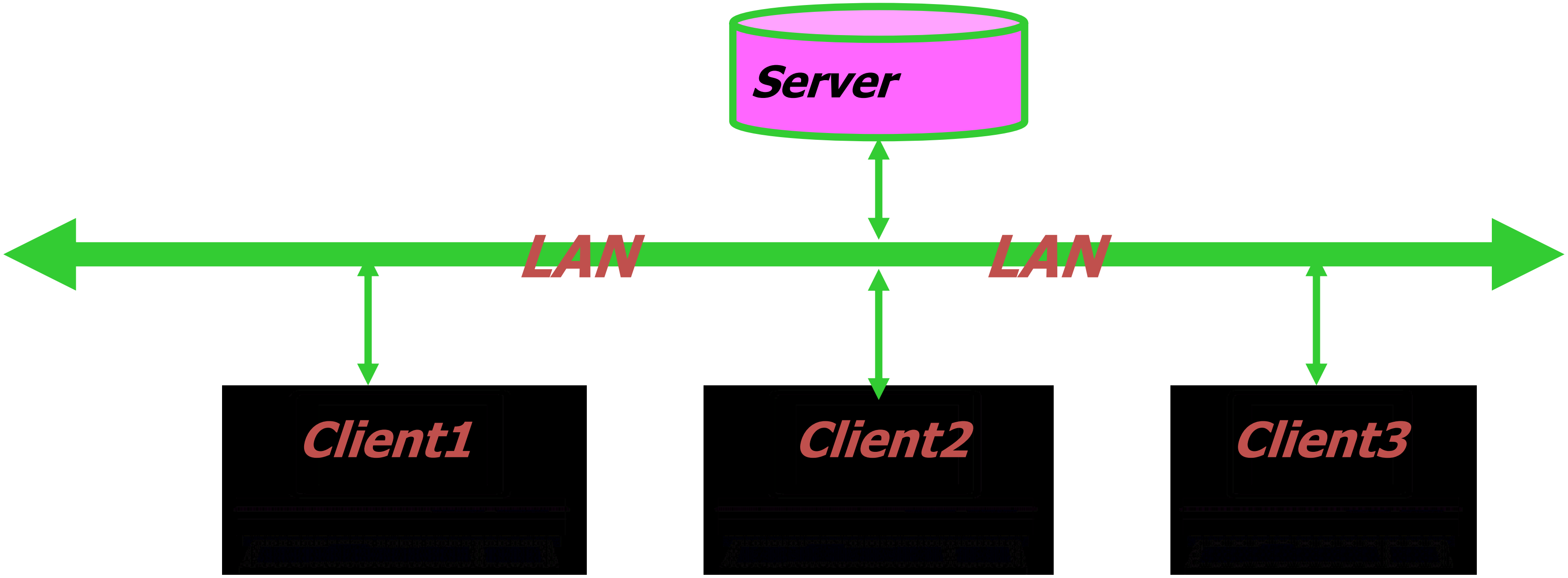
Main types of LAN

- Resource sharing
- Client/Server Model

Resource sharing:

- Allows all network users access to all internal & external resources
- Easy to implement & ideally suited to smaller network

Client/Server Model:



- Used a powerful computer that runs a network operating system and act as the SERVER
- CLIENT is a networked information requester, usually a PC, that can query information from a server

Networking Supports

- Processed and acquired image transfer
- Integration of all image manipulation
- Electronic data (patient demographics, simulation parameters, treatment planning parameters) transfer
- Record and verification
- Patient related event tracking
- Easy accessibility, storage and maintenance of data.

Transfer of images

- Confirm ID
- Confirm nomenclature
- Confirm supplementary imaging sequences required (MRI/PET)and format availability and compatibility
- Confirm phases required for dynamic imaging

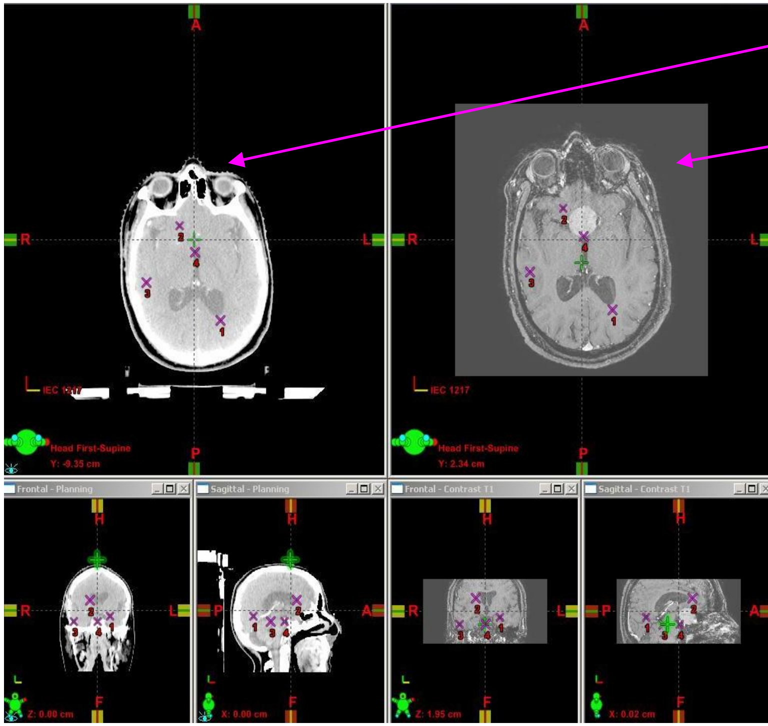
IMAGE REGISTRATION

- Image registration allows use of complementary features of different scan types.
- Employs a unique algorithm that allows full voxel to voxel intensity match, Image Fusion automatically correlates thousands of points from two image sets, providing true volumetric fusion of anatomical data sets.
- This requires calculation of 3D transformation that relates coordinates of a particular imaging study to planning CT coordinates.
- Various registration techniques include
  - Point-to-point fitting,
  - Line or curve matching
  - Surface or topography matching
  - Volume matching

CT IMAGE

MRI IMAGE

POINT TO POINT MATCHING



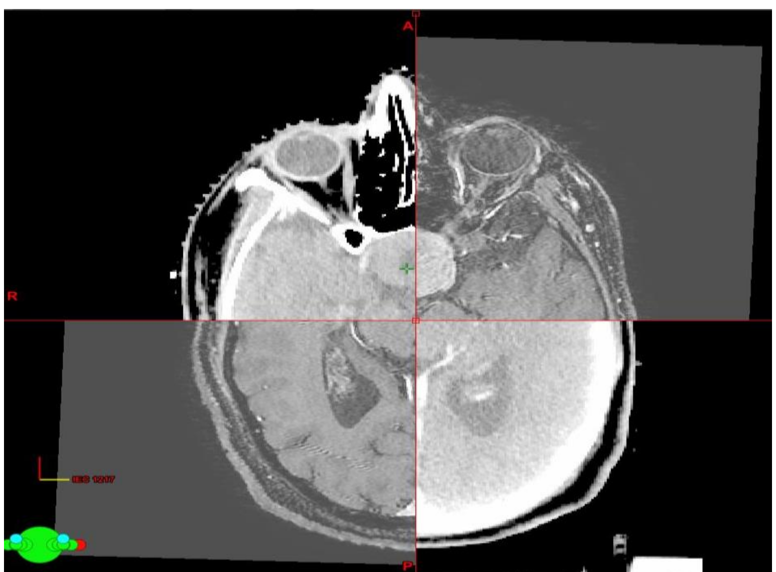
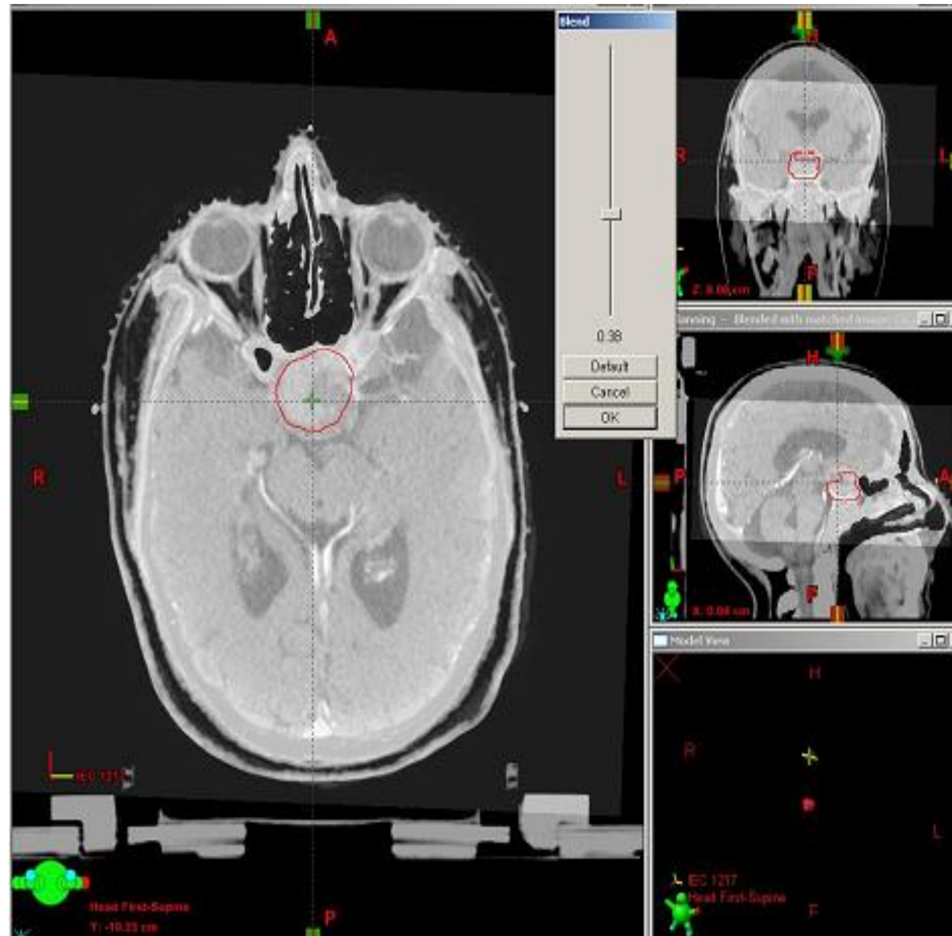


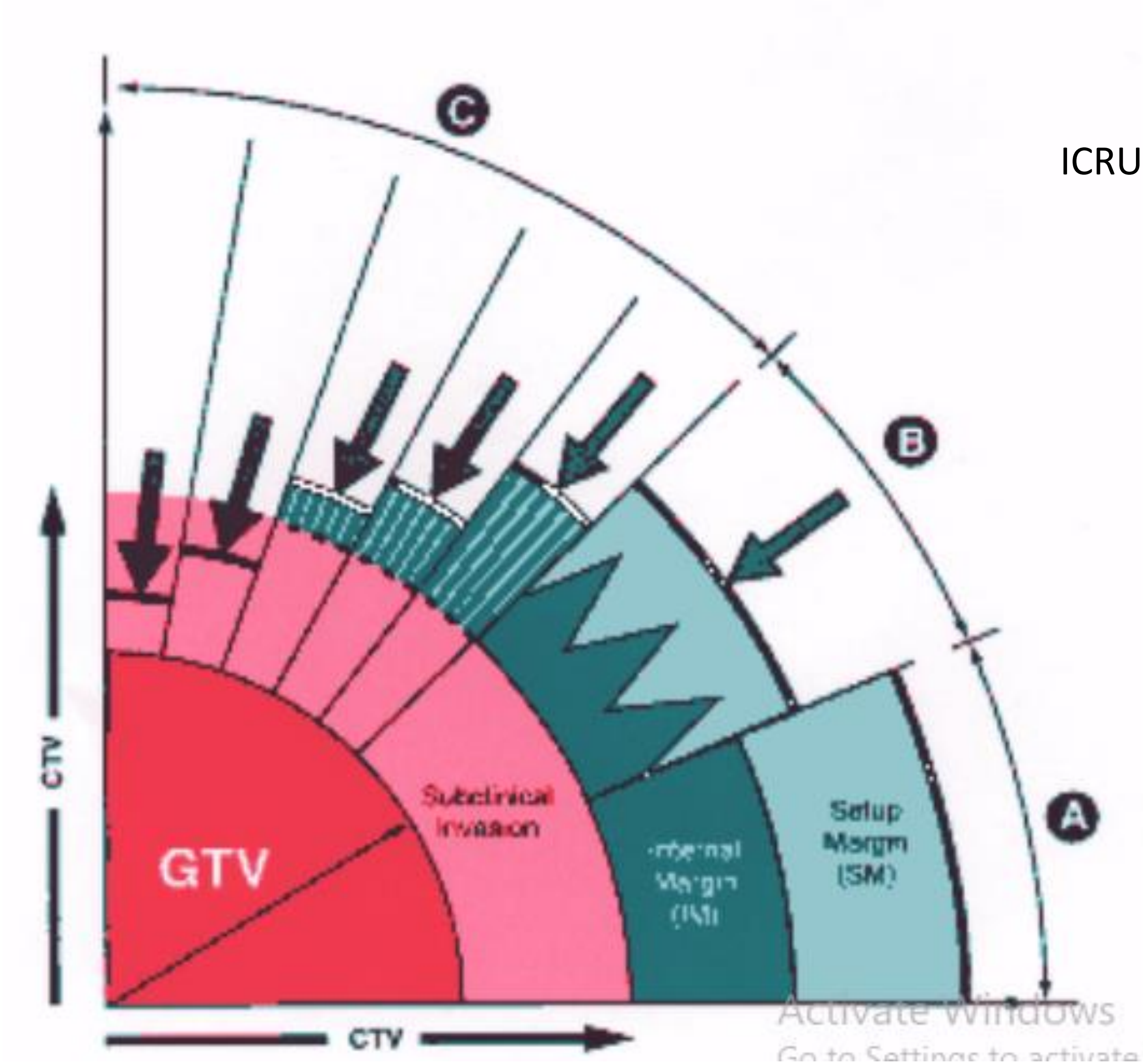
IMAGE FUSION



CONTOURING ON BLENDED IMAGE

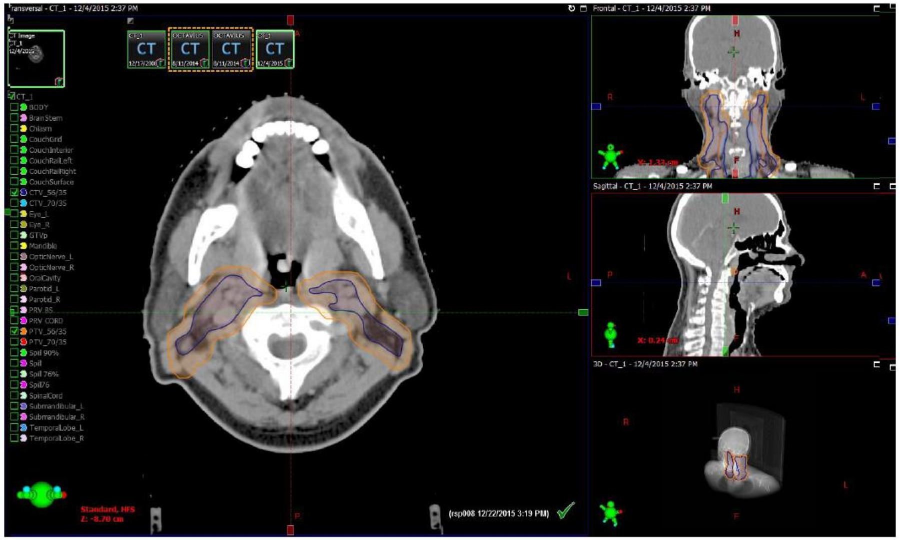
Delineation

ICRU 50 & 62



DELINEATION

- Limitations of conventional imaging in delineating gross tumor
- Optimal window level settings a pre requisite
- OAR delineation – multiple challenges ,IOV.
- Biological imaging such as PET a useful adjunct , limited by spatial resolution and co registration issues when not obtained as planning imaging
- Variations in the definition of the CTV
- PTV margins – lack of population based and institutional data / isotropic vs anisotropic margins



AND ITS INADEQUACIES …..

Clinical Investigation: Genitourinary Cancer

Postoperative Radiotherapy in Prostate Cancer: The Case of the Missing Target

Jennifer Croke, M.D.,* Shawn Malone, M.D., F.R.C.P.C.,* Nicolas Roustan Delatour, M.D.,† Eric Belanger, M.D., F.R.C.P.C.,† Leonard Avruch, M.D., F.R.C.P.,‡ Christopher Morash, M.D., F.R.C.S.C.,§ Cathleen Kayser, M.R.T.(T.), C.M.D.,* Kathryn Underhill, B.Sc.(Hons.),* and Johanna Spaans, M.Sc.*

*From the *Division of Radiation Oncology, The Ottawa Hospital Cancer Centre, The University of Ottawa, Ottawa, Ontario, Canada; Departments of †Pathology and Laboratory Medicine and ‡Radiology, and §Division of Urology, The Ottawa Hospital, The University of Ottawa, Ottawa, Ontario, Canada*

Table 3 Percentage of MRI-defined prostate volume not adequately covered by the consensus guideline CTVs

	CTV definition				
3DCRT technique	CTV-PMH (mean; range)	CTV-RTOG	CTV-FROGG	CTV-EORTC	Overall
Four-field	27% (4–61%)	29% (5–65%)	43% (17–67%)	52% (23–77%)	38%
Six-field	24% (0.2–61%)	29% (4–65%)	39% (16–67%)	49% (19–77%)	35%

Results: Gross tumor was visible in 18 cases. In all 20 cases, the consensus CTVs did not fully cover the MRI-defined prostate. On average, 35% of the prostate volume and 32% of the gross tumor volume were missed using six-field 3D treatment plans. The entire MRI-defined gross tumor volume was completely covered in only two cases (six-field plans). The expanded PTVs did not cover the entire prostate bed in 50% of cases. Prostate base and mid-zones were the predominant site of inadequate coverage.

Conclusions: Current postoperative CTV guidelines do not adequately cover the prostate bed and/or gross tumor based on preoperative MRI imaging. Additionally, expanded PTVs do not fully cover the prostate bed in 50% of cases. Inadequate CTV definition is likely a major contributing factor for the high risk of relapse despite adjuvant XRT. Preoperative imaging

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PTV MARGINS – MULTIPLE RECIPES

Table 2. Summary of Published Margin Recipes for Target, Respiration (Target) and Organs of Risk

Author	*Application*	*Recipe*	*Assumptions*
Bel et al, 1996b[59]	Target	$0.7\ \sigma$	Random errors only (linear approximation) Monte Carlo
Antolak and Rosen, 1999[81]	Target	$1.65\ \sigma$	Random errors only, block margin?
Stroom et al, 1999[51]	Target	$2\ \Sigma + 0.7\ \sigma$	95% dose to on average 99% of CTV tested in realistic plans
Van Herk et al, 2000[43]	Target	$2.5\ \Sigma + 0.7\ \sigma$ or (more correct): $2.5\ \Sigma + 1.64\ (\sigma - \sigma_p)$	Minimum dose to CTV is 95% for 90% of patients. Analytical solution for perfect conformation
McKenzie et al, 2000[60]	Target	$2.5\ \Sigma + \beta\ (\sigma - \sigma_p)$	Extension of van Herk et al for fringe dose due to limited number of beams
Parker et al, 2002[82]	Target	$\Sigma + \sqrt{(\sigma^2 + \Sigma^2)}$	95% minimum dose and 100% dose for 95% of volume. Probability levels not specified
Van Herk et al, 2002[52]	Target	$2.5\ \Sigma + 0.7\ \sigma - 3$ mm or (more correct): $\sqrt{2.7^2\ \Sigma^2 + 1.6^2\ \sigma^2} - 2.8$ mm	Monte Carlo based test of 1% TCP loss due to geometrical errors for prostate patients
Van Herk et al, 2003[69]	Target	$M - 2$ mm $M - 5$ mm	Correction for nonuniform cell density
Ten Haken et al, 1997[83] and Engelsman et al, 2001[84]	Respiration (liver and lung)	0 A	No margin for respiration but compensation by dose escalation to iso-NTCP, reducing target dose homogeneity constraints
McKenzie et al 2000[50]	Respiration	A	Margin for respiration on top of other margins when respiration dominates other errors
van Herk et al, 2003[47]	Respiration (lung)	0.25 A (caudally) 0.45 A (cranially)	Margin for (random) respiration combined with 3 mm random SD, when respiration dominates other errors ($A > 1$ cm)
McKenzie et al, 2002[85]	OAR	$1.3\ \Sigma +/- 0.5\ \sigma$	Margins for small and/or serial organs at risk in low (+) or high (−) dose region

Abbreviations: Σ, SD of systematic errors; σ, SD of random errors; σ_p, describes width of beam penumbra fitted to a Gauss function; A, peak-peak amplitude of respiration; M, margin before adjustment for described effect.

Treatment planning

History of computational system in RT

- 1st commercial TPS – 1960s
  Operated on specialized hardware

- Evolution of computer technology during 1970's and development of CT led to revolution in CT based computerized treatment planning during 1970 – 1980.

- Current TPS has the capability to represent the patient anatomy and dose distribution in 3 D models

- Computerized treatment planning is a rapidly evolving modality, relying heavily on both hardware and software.

TPS hardware (Graphics display)

Graphics display must be capable of rapidly displaying high resolution images. The resolution is sub-millimeter or better so as not to distort the input.

Graphics speed can be enhanced with video cards and hardware drivers (graphics processor).

TPS hardware (Memory)

- Memory and archiving functions are carried through
  a) removable media:
  - re-writable hard-disks
  - optical disks
  - DVDs
  - DAT tape

  b) network on:
  - a remote computer
  - a server
  - the linac with its record-and-verify system

- Archiving operations may be carried out automatically during low use periods of the day.

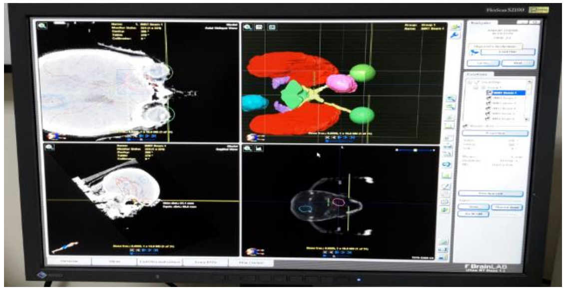
TPS Software

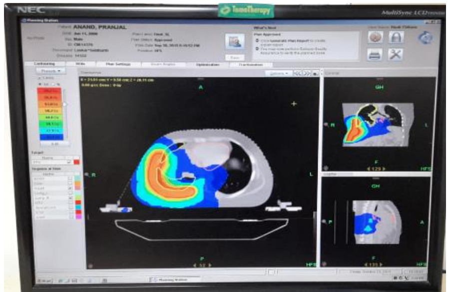
software components:

- The computer operating system (plus drivers, etc.)
- Utilities to enter treatment units and associated dose data
- Utilities to handle patient data files
- Contouring structures such as anatomical structures, target volumes, etc.
- Dose calculation (Algorithms)
- Treatment plan evaluation
- Hardcopy devices
- Archiving
- Backup to protect operating system and application programs

Commercial TPS

Varian – Eclipse
Elekta – Monaco & Oncentra
Raysearch – RayStation
Brainlan – iPlan/Elements
Tomotherapy
Prowess ….and many others





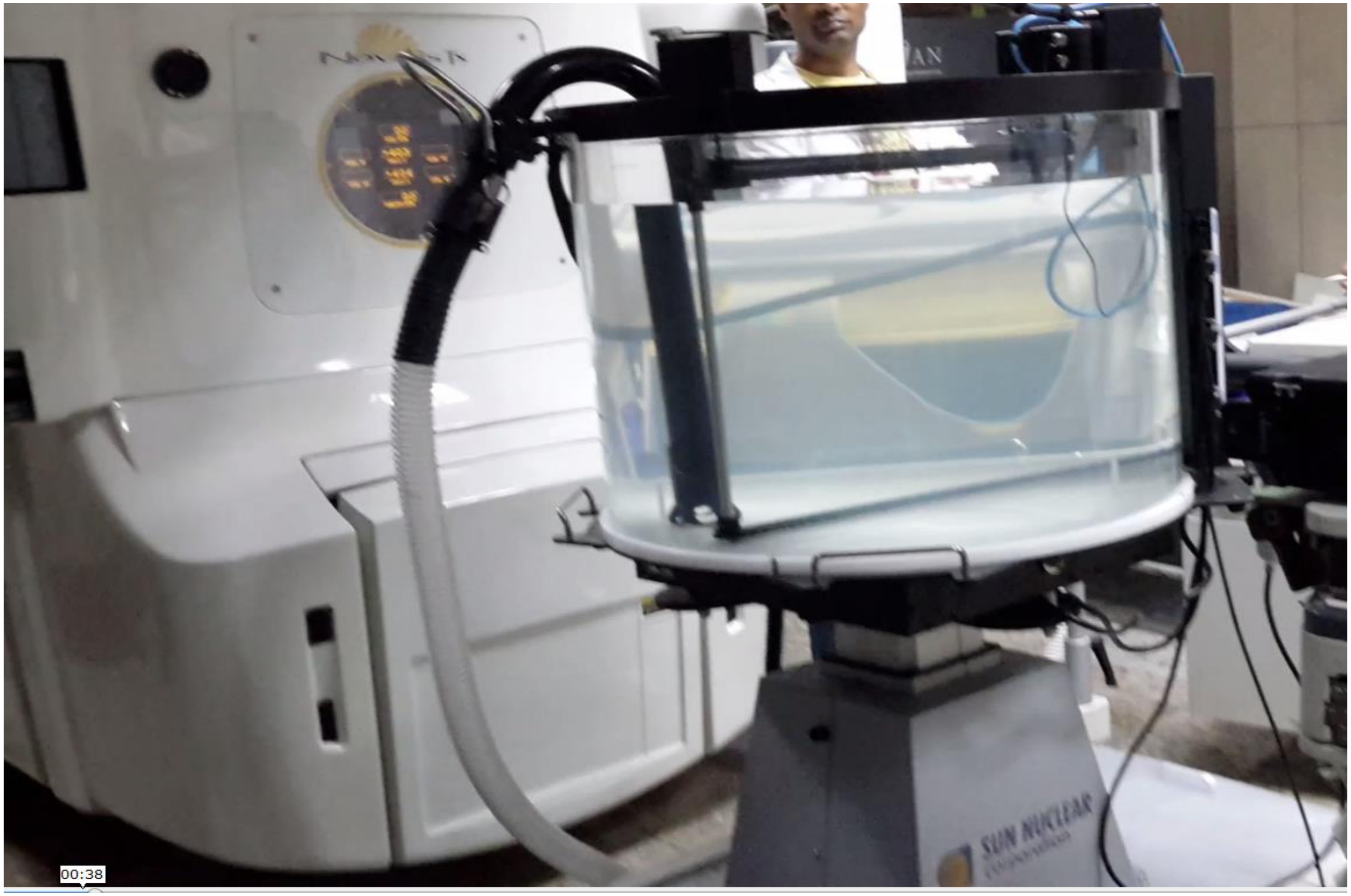
Typical beam data requirement for TPS

- Without feeding the beam data into the TPS it cannot make any calculations.
- The beam data acquire and fed into the TPS should be accurate and it should be measured by instruments which are calibrated.

For modeling a TPS the following data is required

- Machine data
- Beam data
- Patient data

Beam Data Acquisition System or Radiation Field Analyzer (RFA)



Beam data contd.

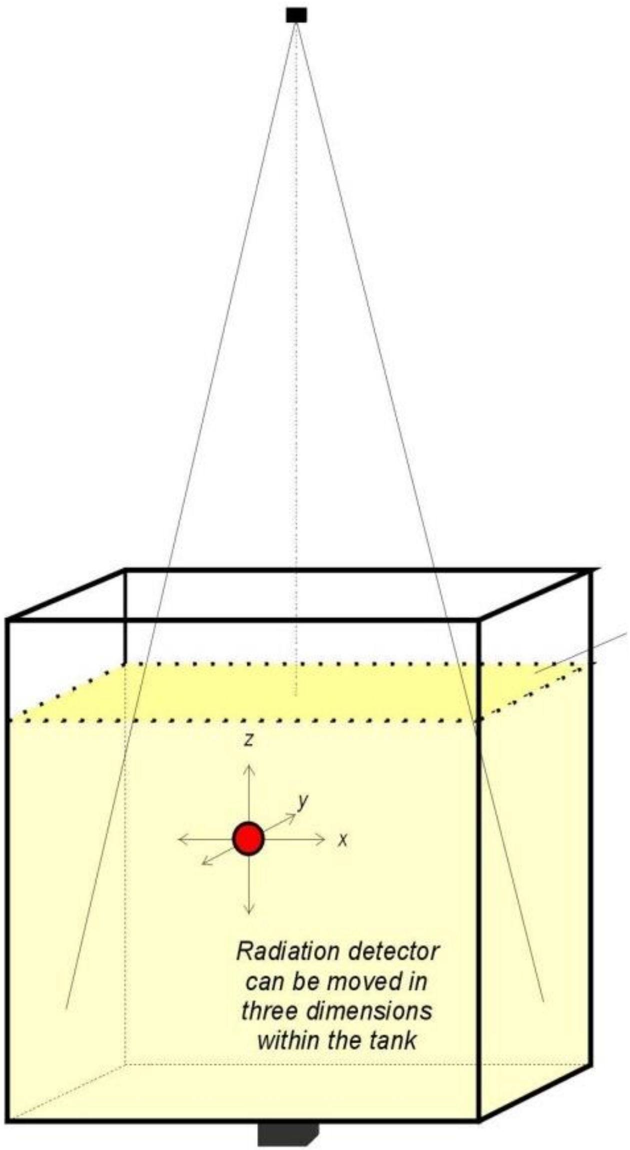
Typical photon beam data sets include:

Various combination of field size, energy and depth

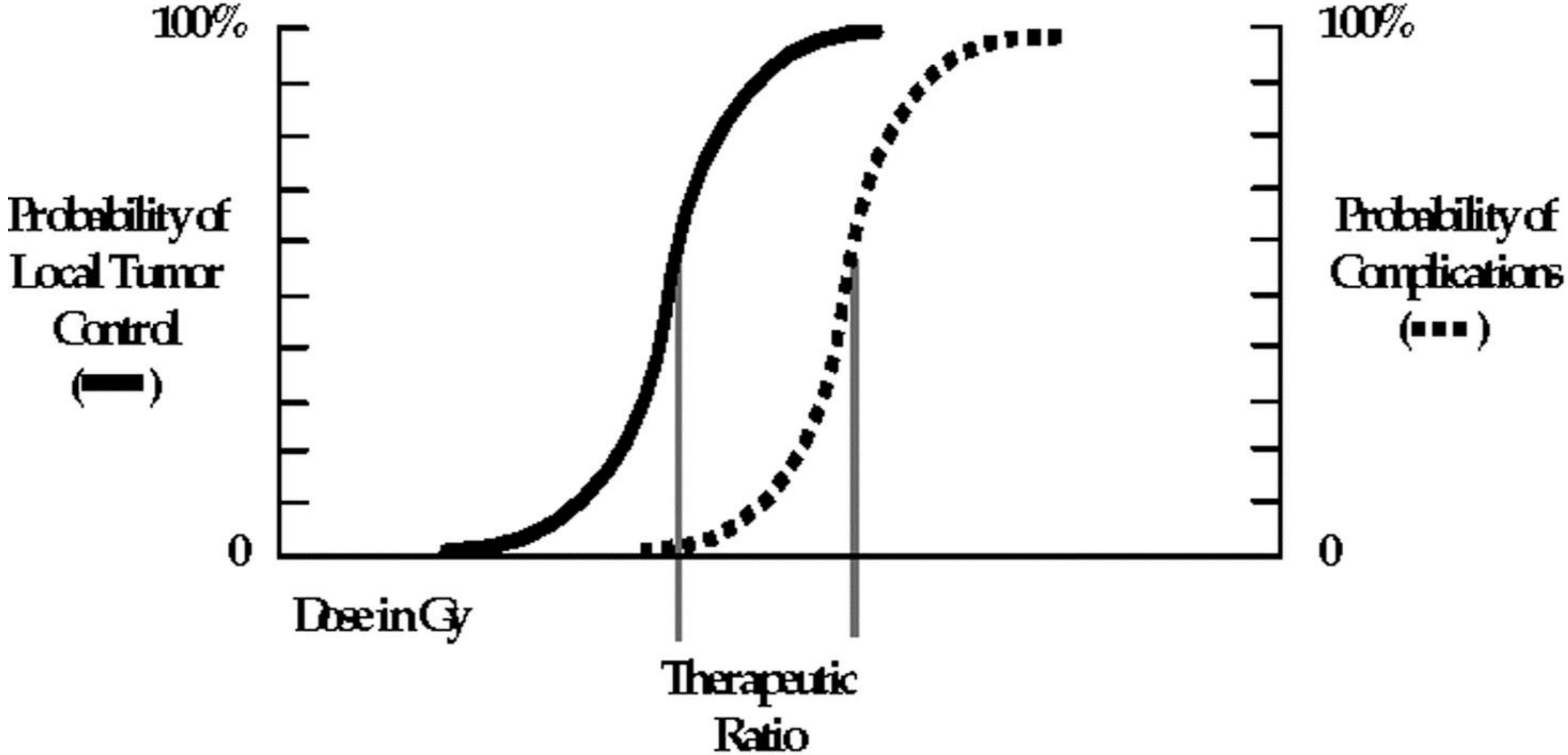
- Central axis PDDs
- Off Axis Ratios
- Output factors
- Crossline, inline, diagonal beam profiles.

IMRT/VMAT

- MLC transmission
- Dosimetric leaf gap, Jaw transmission
- Leaf Speed, Dose Rate



Therapeutic Ratio

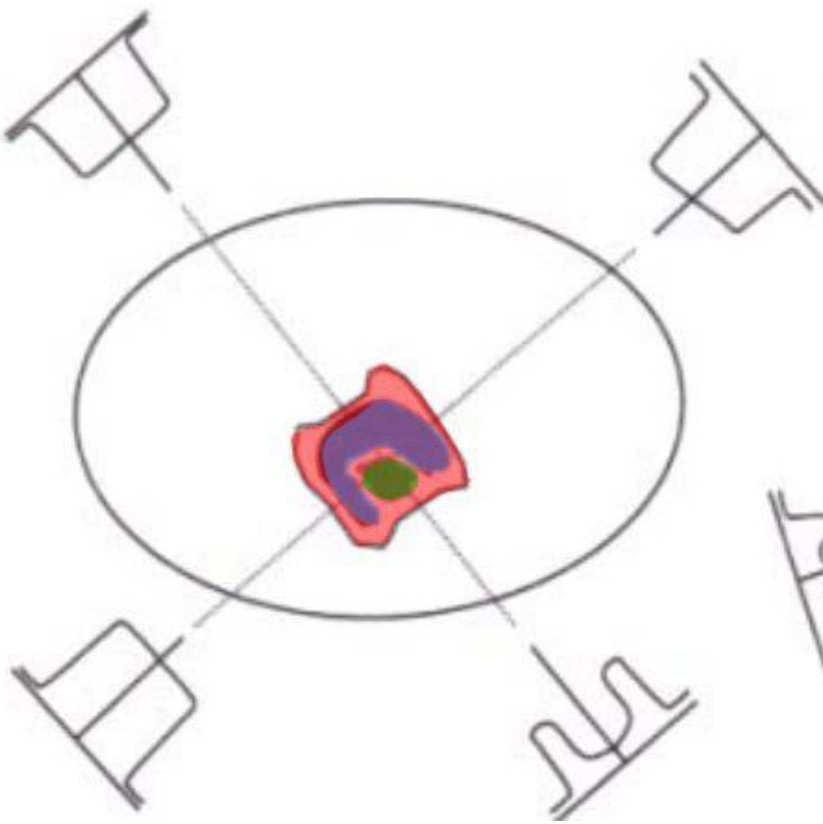


Sensitization ← → **Protection**

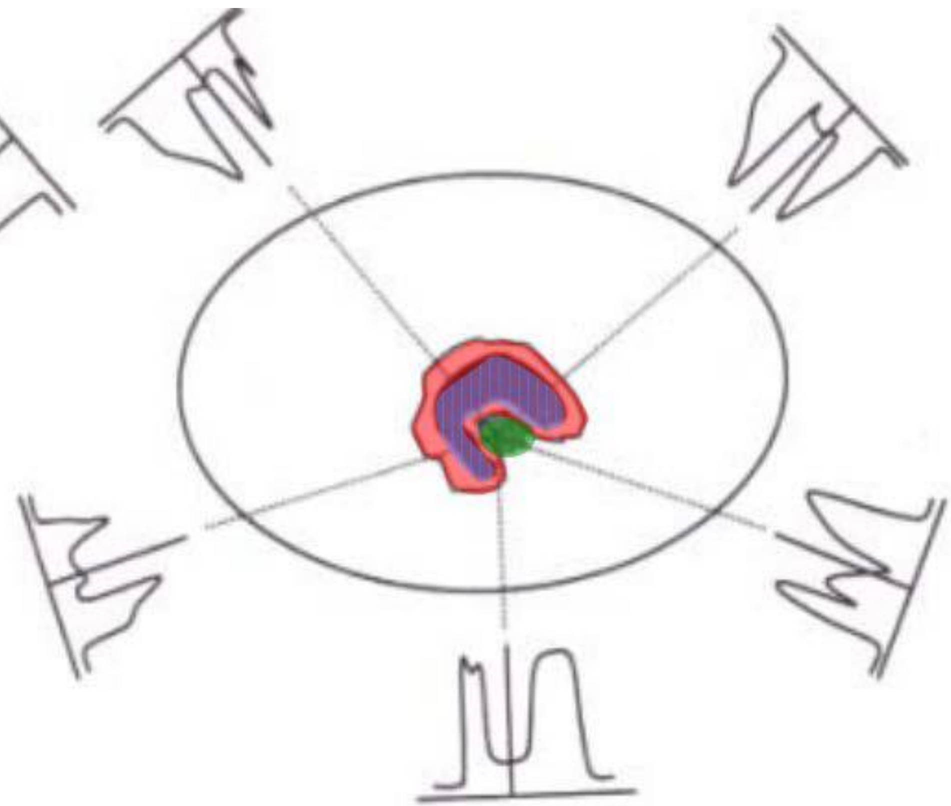
Sensitization	Protection
Chemotherapy	3-D Conformal radiation therapy
Oxygen	Intensity modulated radiation therapy
Hypoxic cell sensitizers	Radioprotectors

Evolution and principles

3DCRT

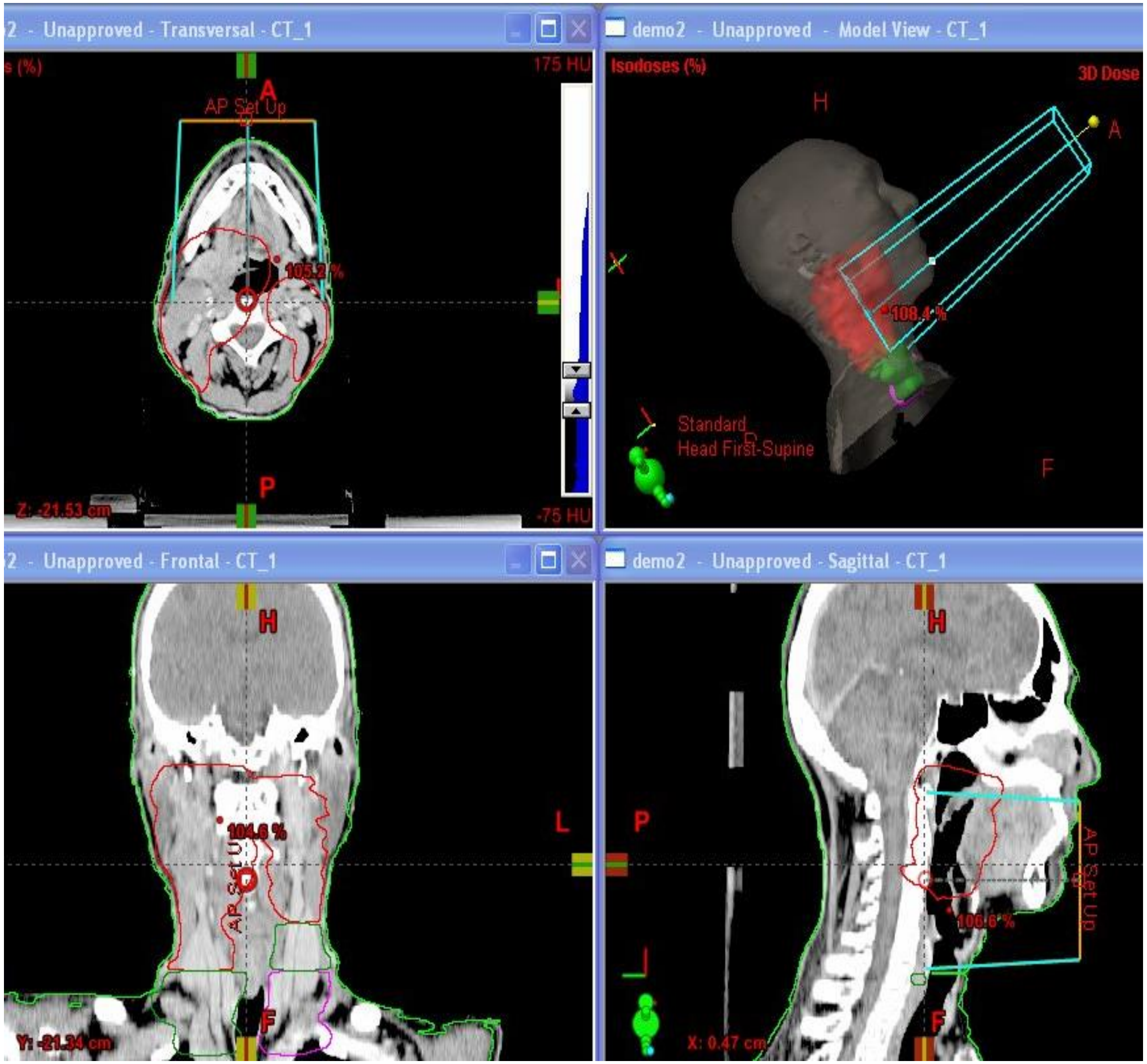


IMRT/VMAT

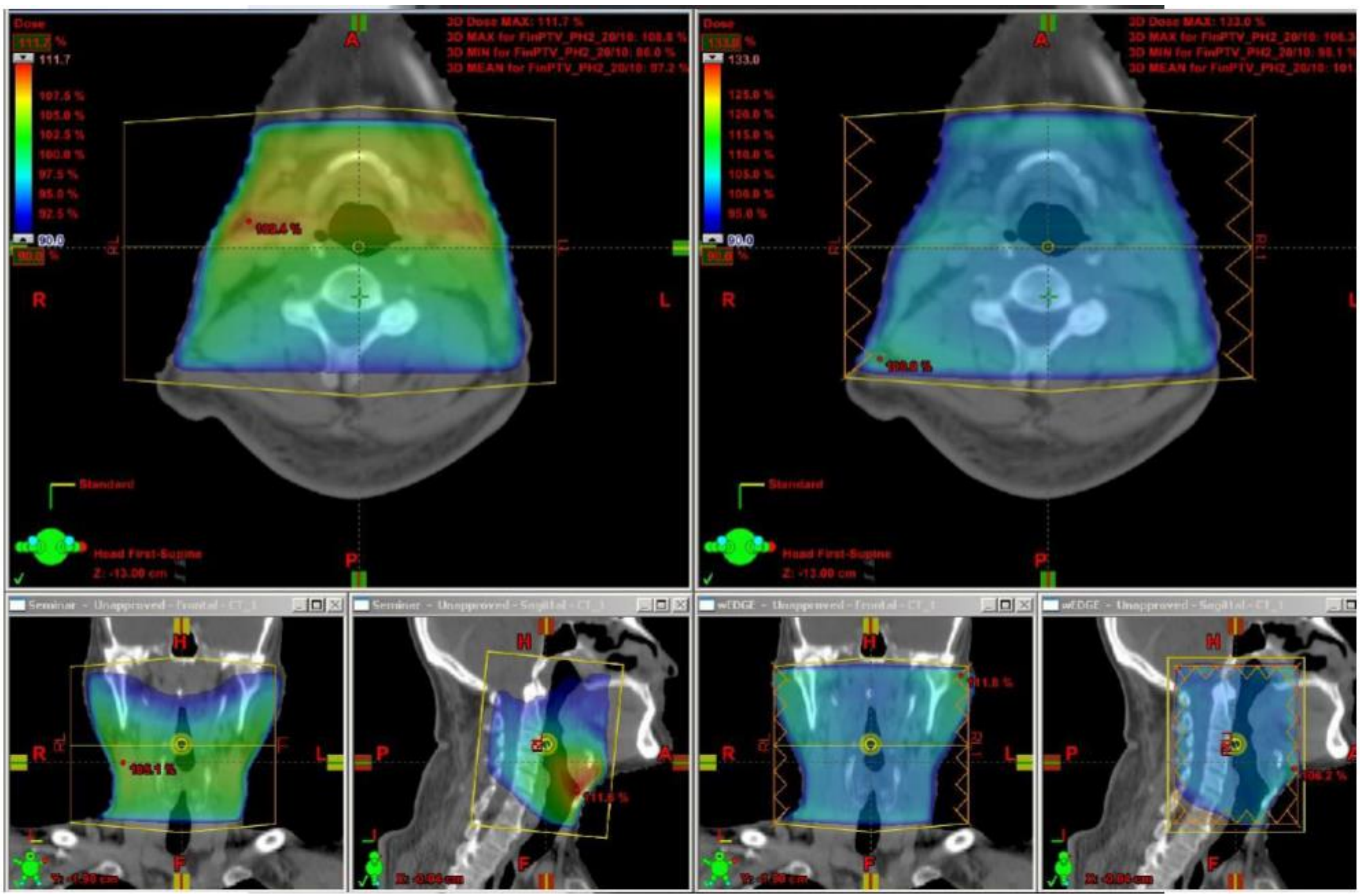


Planning tips -Isocenter placement

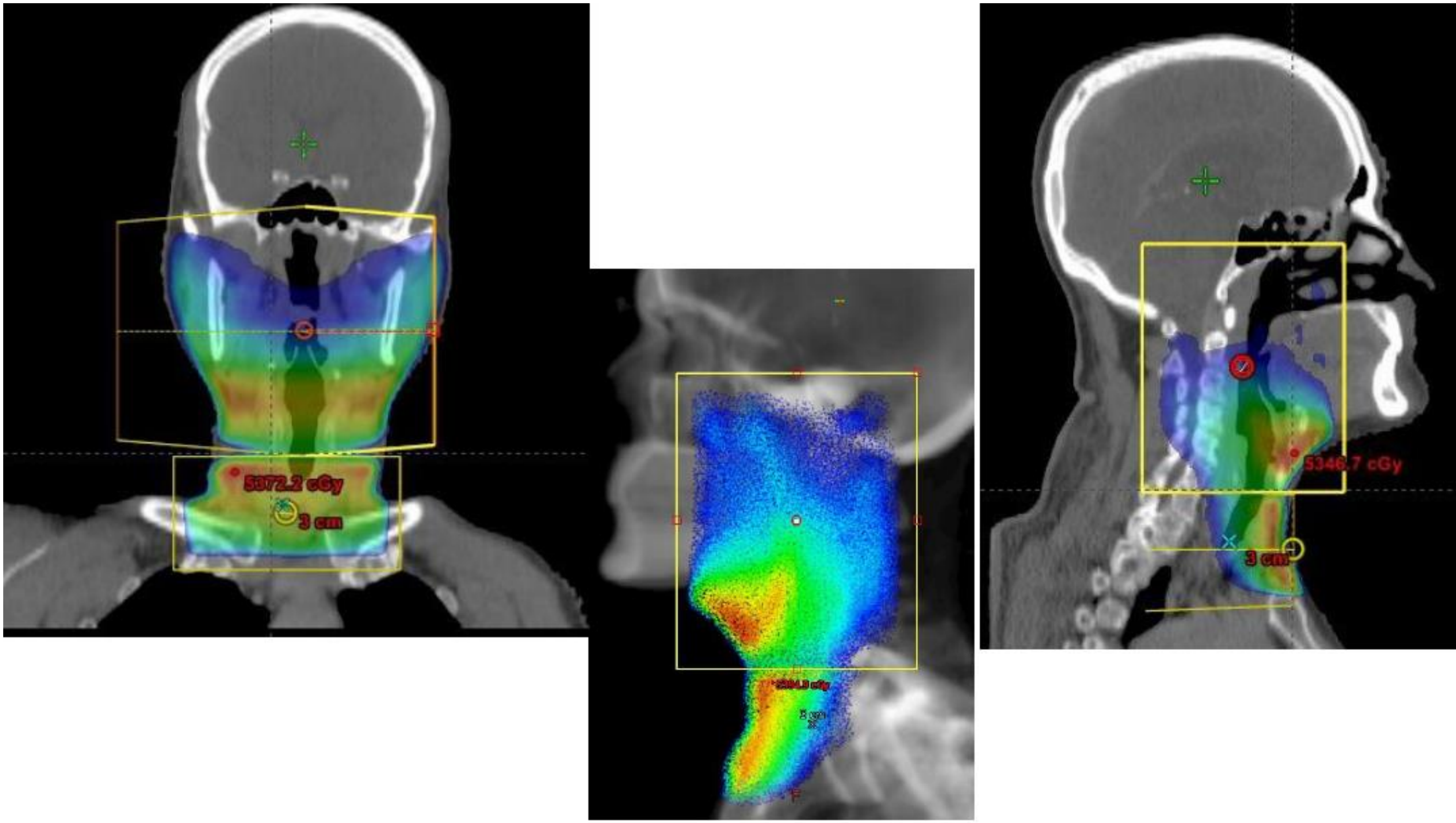
- Preferably in PTV high risk
- Avoid slanting surface
- Ease of daily setup for treatment



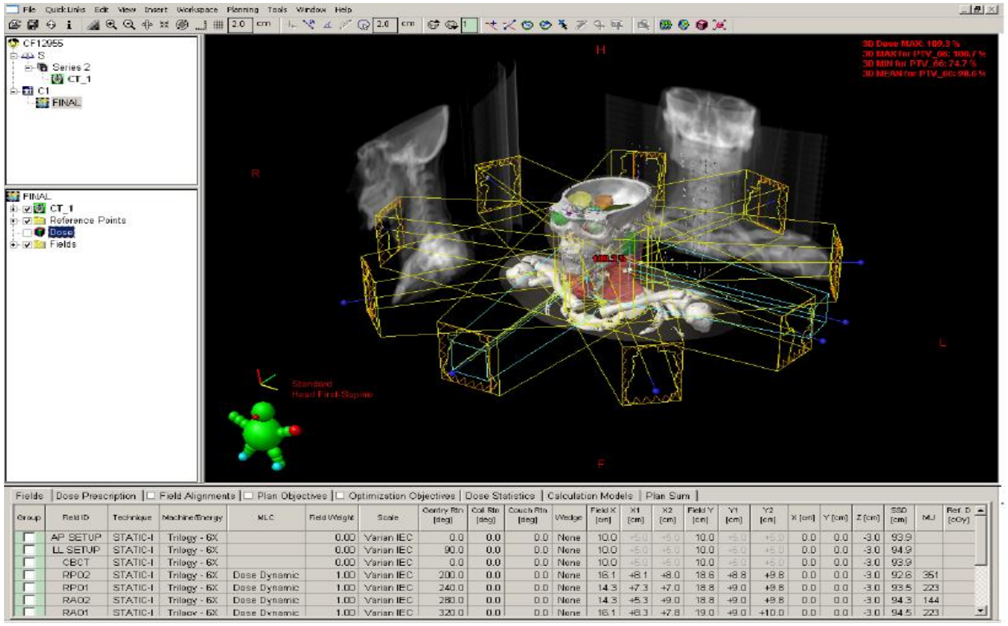
Planning: Oral cavity, tongue

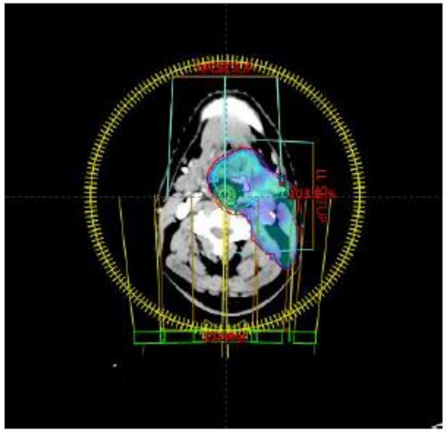


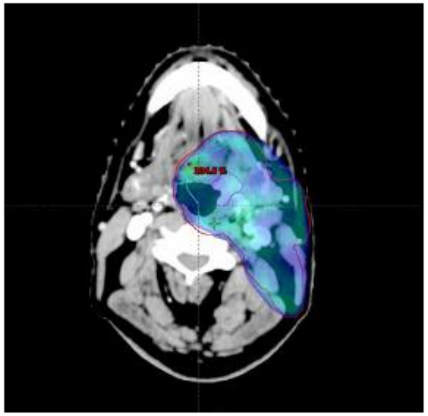
3 field technique

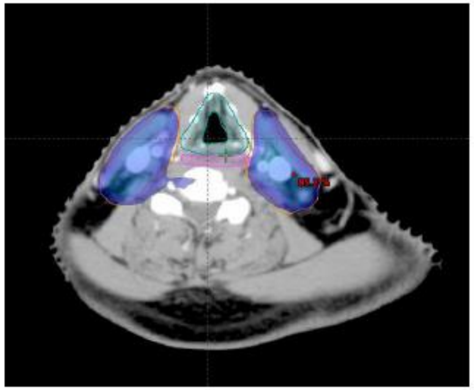


IMRT & VMAT


File QuickLinks Edit View Insert Workspace Planning Tools Window Help
CF12955
Series 2
CT_1
C1
FINAL
Reference Points
Dose
Fields
H
R
L
F
Standard
Head First-Supine
Fields | Dose Prescription | Field Alignments | Plan Objectives | Optimization Objectives | Dose Statistics | Calculation Models | Plan Sum
Group | Field ID | Technique | Machine/Energy | MLC | Field Weight | Scale | Gantry Rtn [deg] | Coll Rtn [deg] | Couch Rtn [deg] | Wedge | Field X [cm] | X1 [cm] | X2 [cm] | Field Y [cm] | Y1 [cm] | Y2 [cm] | X [cm] | Y [cm] | Z [cm] | SSD [cm] | MU | Ref. D [cGy]
AP SETUP | STATIC-I | Trilogy - 6X | | 0.00 | Varian IEC | 0.0 | 0.0 | 0.0 | None | 10.0 | +5.0 | +5.0 | 10.0 | +5.0 | +5.0 | 0.0 | 0.0 | -3.0 | 93.9
LL SETUP | STATIC-I | Trilogy - 6X | | 0.00 | Varian IEC | 90.0 | 0.0 | 0.0 | None | 10.0 | +5.0 | +5.0 | 10.0 | +5.0 | +5.0 | 0.0 | 0.0 | -3.0 | 94.9
CBCT | STATIC-I | Trilogy - 6X | | 0.00 | Varian IEC | 0.0 | 0.0 | 0.0 | None | 10.0 | +5.0 | +5.0 | 10.0 | +5.0 | +5.0 | 0.0 | 0.0 | -3.0 | 93.9
RPO2 | STATIC-I | Trilogy - 6X | Dose Dynamic | 1.00 | Varian IEC | 200.0 | 0.0 | 0.0 | None | 16.1 | +8.1 | +8.0 | 18.6 | +8.8 | +9.8 | 0.0 | 0.0 | -3.0 | 92.6 | 351
RPO1 | STATIC-I | Trilogy - 6X | Dose Dynamic | 1.00 | Varian IEC | 240.0 | 0.0 | 0.0 | None | 14.3 | +7.3 | +7.0 | 18.8 | +9.0 | +9.8 | 0.0 | 0.0 | -3.0 | 93.5 | 223
RAO2 | STATIC-I | Trilogy - 6X | Dose Dynamic | 1.00 | Varian IEC | 280.0 | 0.0 | 0.0 | None | 14.3 | +5.3 | +9.0 | 18.8 | +9.0 | +9.8 | 0.0 | 0.0 | -3.0 | 94.3 | 144
RAO1 | STATIC-I | Trilogy - 6X | Dose Dynamic | 1.00 | Varian IEC | 320.0 | 0.0 | 0.0 | None | 16.1 | +8.3 | +7.8 | 19.0 | +9.0 | +10.0 | 0.0 | 0.0 | -3.0 | 94.5 | 223







Plan Evaluation, DVH Analysis

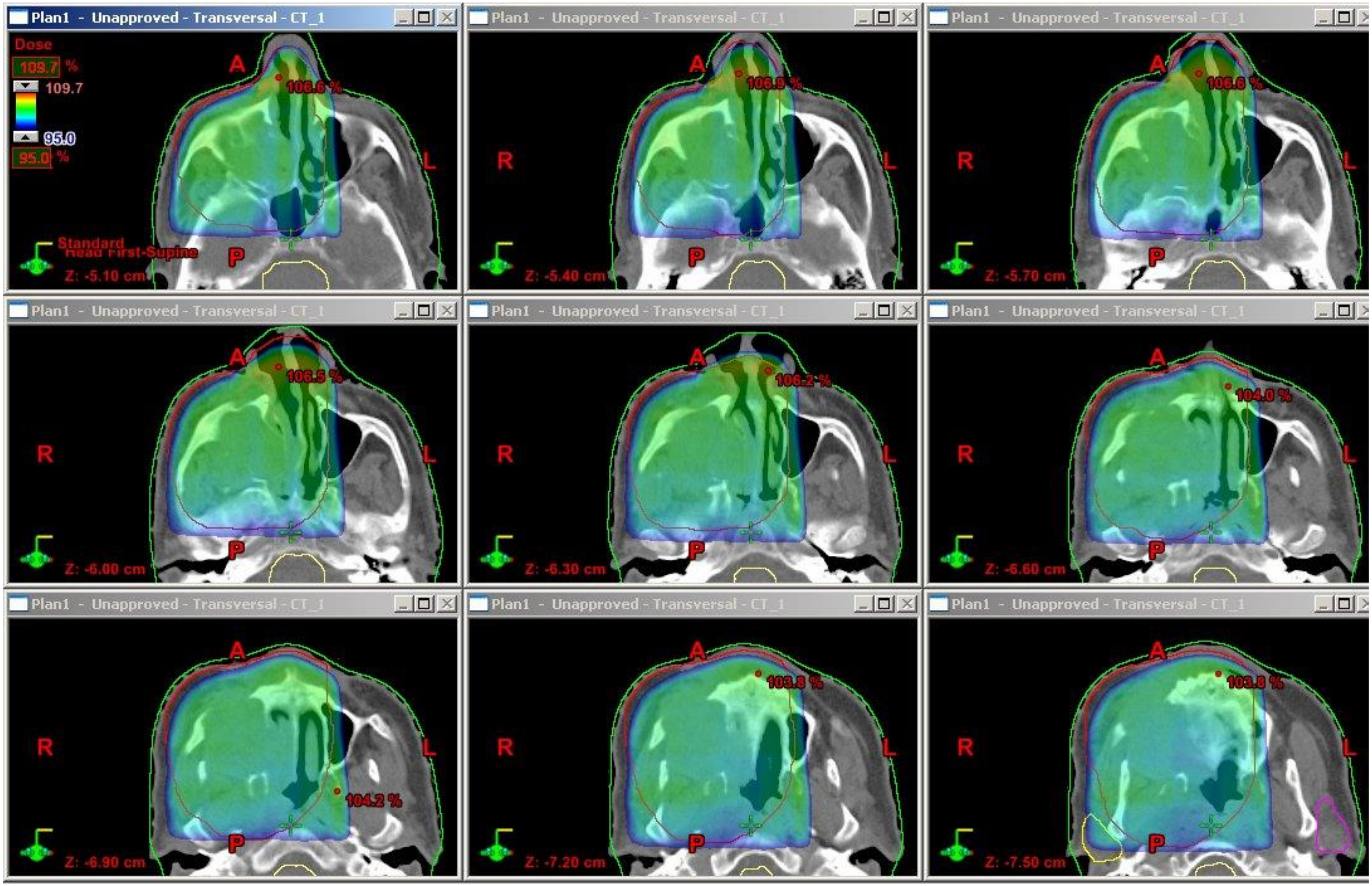
Acceptable Criterion

- Homogenous dose distribution through out the PTV is desirable.
- At least 95% of tumor volume should receive 95% of Prescribed Dose
- Inhomogeneity should be within 95 % and 107 % of the prescription dose
- As Low Dose possible to OAR

Evaluation Tools

- Isodose distribution
- Dose Statistics

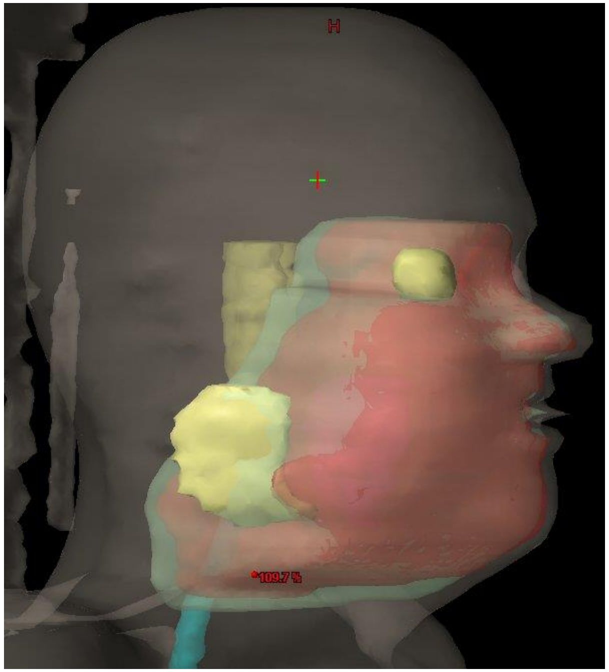
Isodose distribution/Dose wash



Isodose distribution

Isosurface on 3D Display:

Can be used to assess target coverage, they do not convey a sense of distance between the isosurface and the anatomical volumes



Isodose distribution

Disadvantages:

- Ideal if no. of CT slices are small
- Can not determine the volume of HotSpot/ Coldspot

Advantages:

- Location of HotSpot/Coldspot

Dose Statistics

- Provide quantitative information on the volume of the target or critical structure, and on the dose received by that volume.

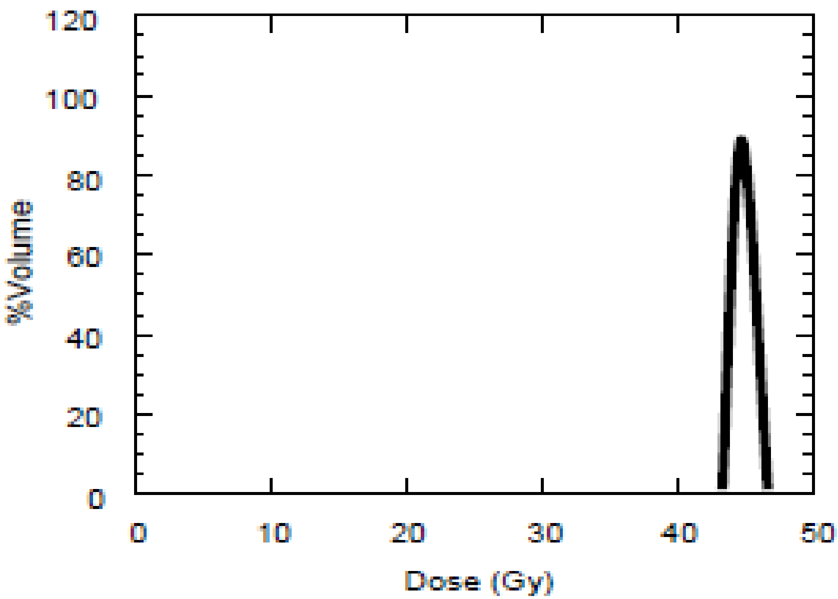
    - Minimum dose to the volume
    - Maximum dose to the volume
    - Mean dose to the volume
    - Dose received by at least 95% of the volume
    - Volume irradiated to at least 95% of the prescribed dose.

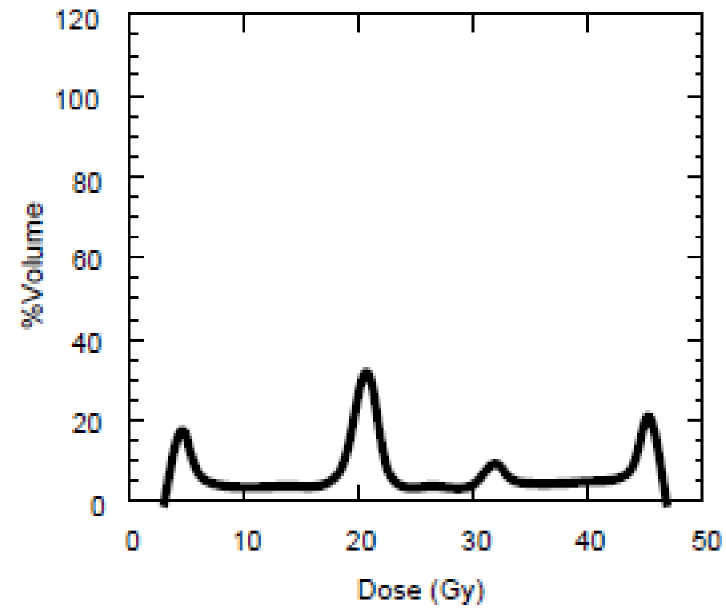
Types of DVH

- Differential (or Direct) DVH
- Cumulative (or Integral) DVH

Differential DVH

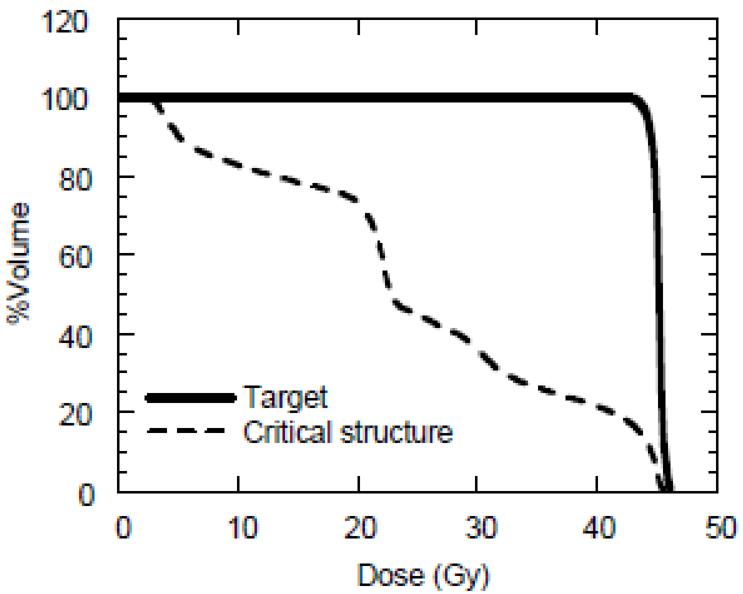
- The ideal DVH for a target volume would be a single column indicating that 100% of the volume receives the prescribed dose.
- For a critical structure, the DVH may contain several peaks indicating that different parts of the organ receive different doses.





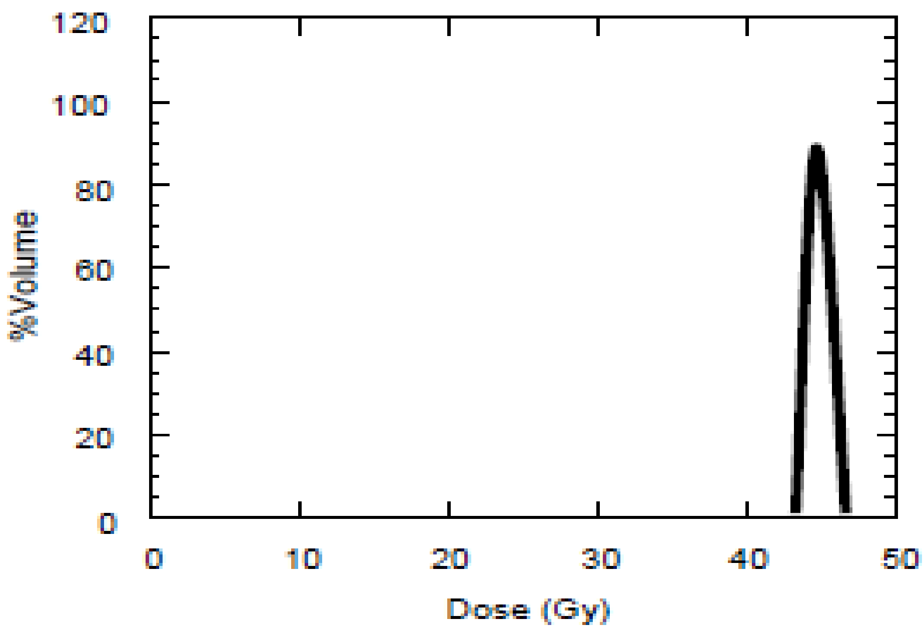
Cumulative DVH

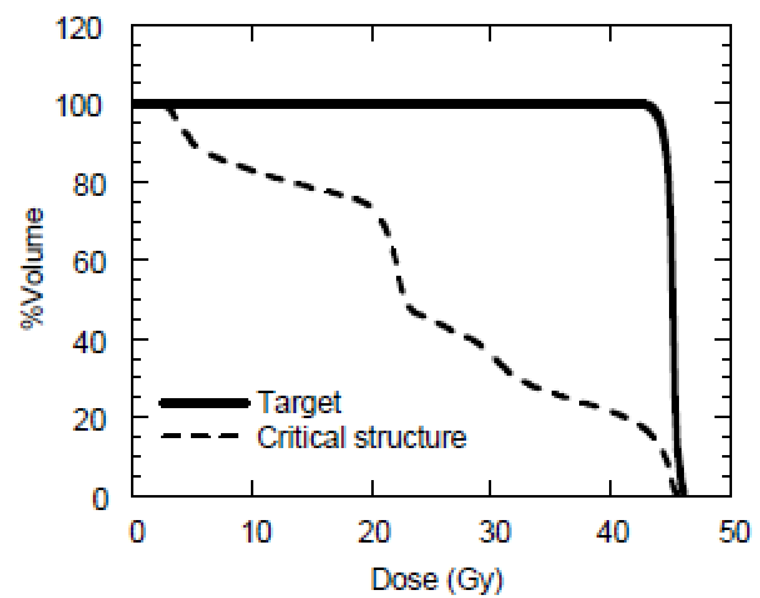
- Plot of entire volume of anatomical structure specified dose or higher dose.
- The computer calculates the volume of the target (or critical structure) that receives at least the given dose and plots this volume (or percentage volume) versus dose.
- All cumulative DVH plots start at 100% of the volume for 0 Gy, since all of the volume receives at least no dose.



Differential or Cumulative?

- “How much of the target is covered by the 95% isodose line?”
- The answer cannot be extracted directly from the direct DVH, since it would be necessary to determine the area under the curve for all dose levels above 95% of the prescription dose.
- For this reason, cumulative DVH displays are more popular.





Hot spots

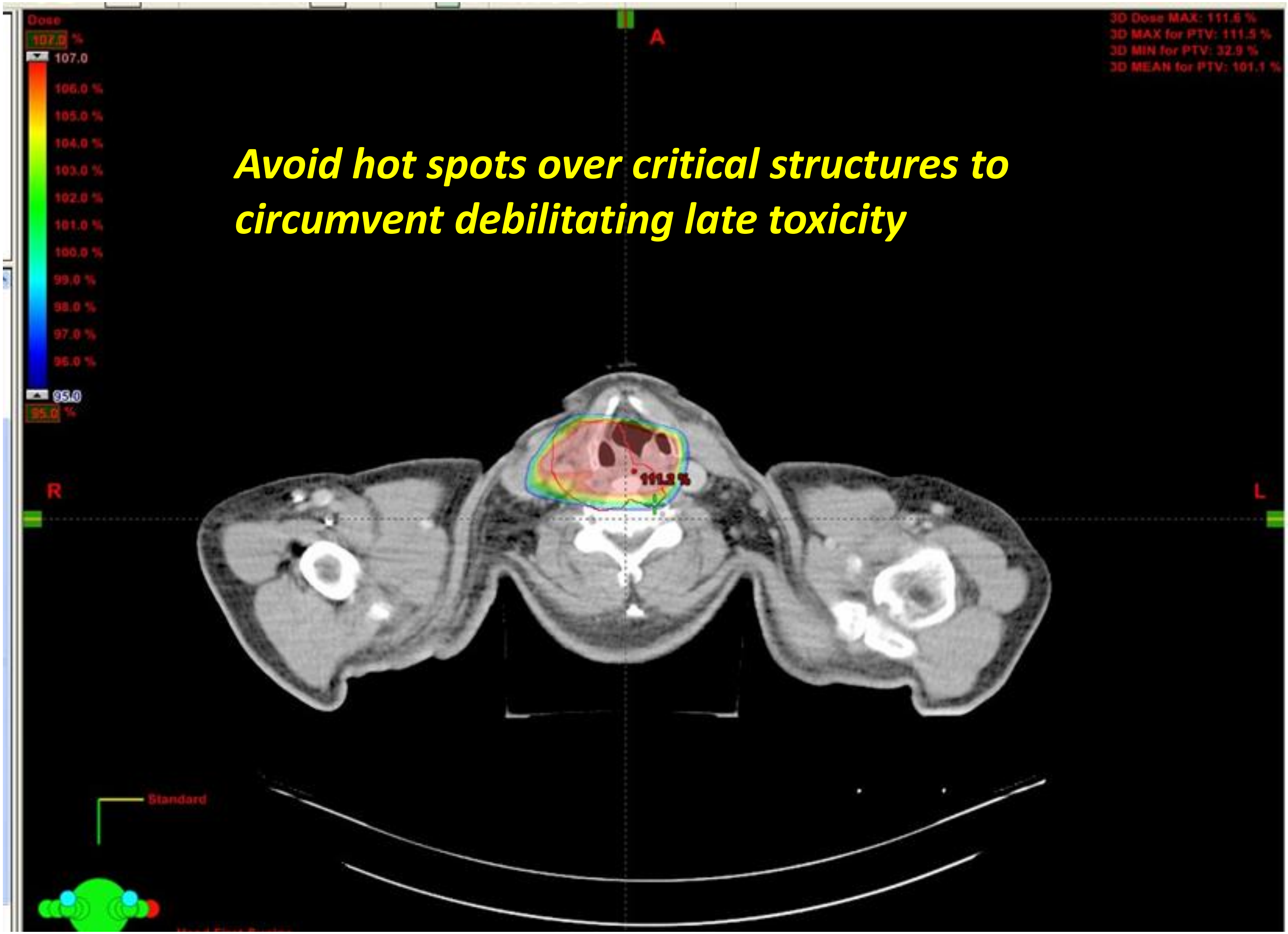
In many situations tissues outside the PTV will receive a relatively large absorbed dose.

A Hot Spot represents a volume outside the PTV, which receives a dose larger than 107 % of the specified PTV dose.

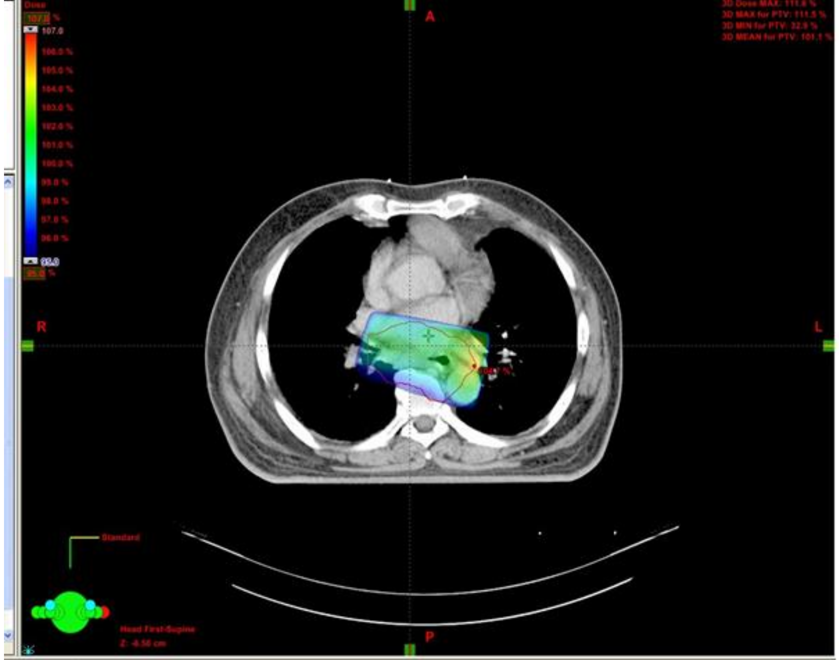
In some cases higher dose may be found in part of PTV where the highest malignant cell concentration may be expected, especially within GTV and such a situation may be of advantage.

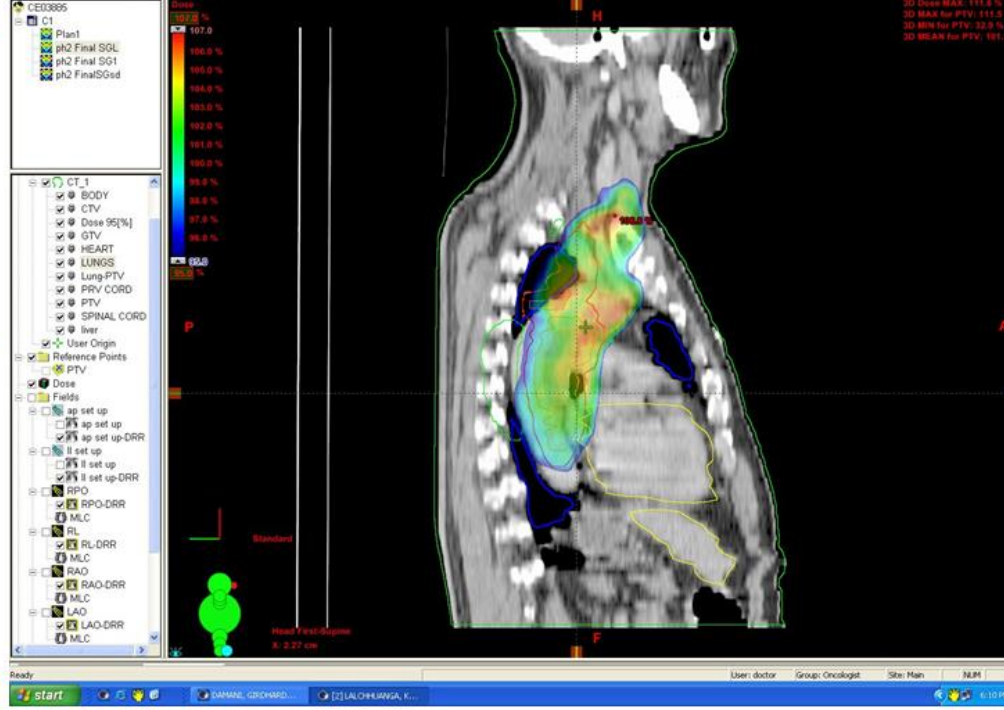
Size and position of the hotspot (<15 mm)

If it occurs in small organs, a dimension smaller than 15 mm has to be considered.



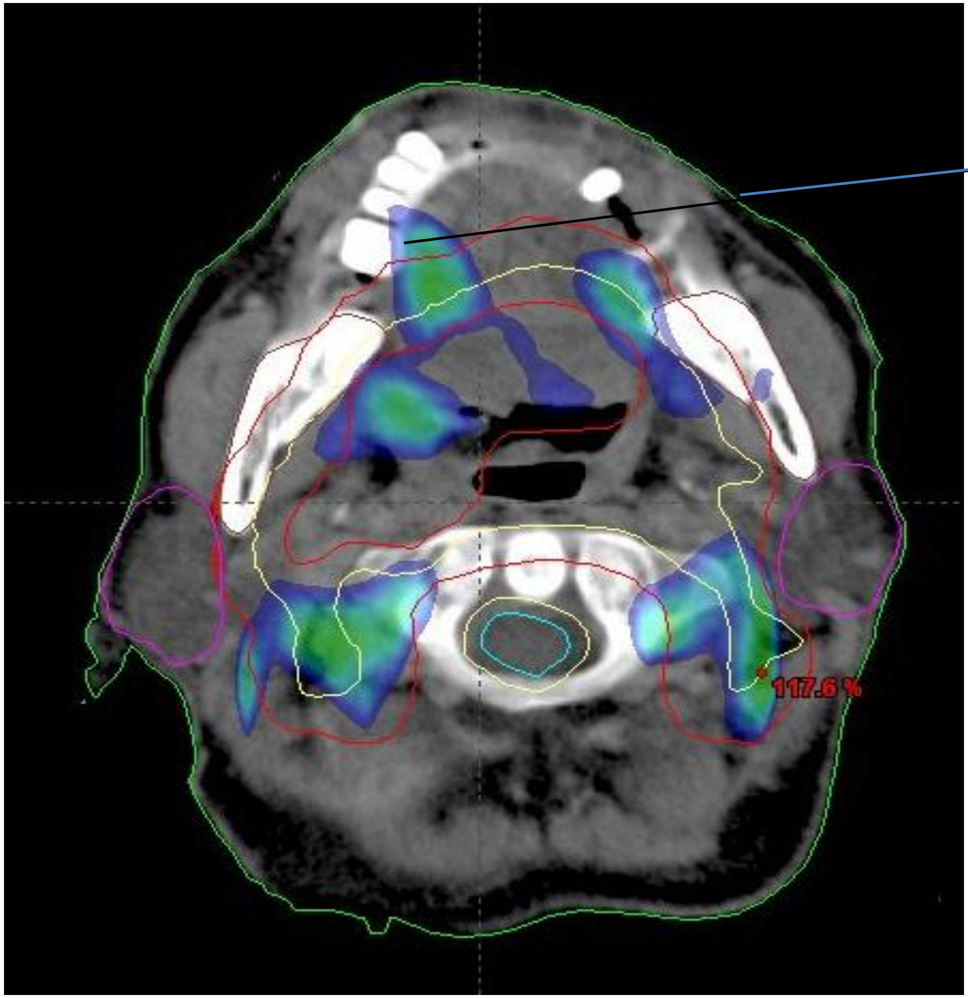
Avoid hot spots over critical structures to circumvent debilitating late toxicity
Dose
107.0
106.0 %
105.0 %
104.0 %
103.0 %
102.0 %
101.0 %
100.0 %
99.0 %
98.0 %
97.0 %
96.0 %
95.0
A
R
L
3D Dose MAX: 111.6 %
3D MAX for PTV: 111.5 %
3D MIN for PTV: 32.9 %
3D MEAN for PTV: 101.1 %
Standard





Ensure target volume coverage and absence of hot spots in all 3 planes : Axial, Saggital and Coronal

Hot spots (+107%)



Hot spot outside PTV, NOT ACCETABLE

Disadvantages

- Exact location of dose in-homogeneity not displayed.

- Dose is only a surrogate of biological consequences.

Conclusion : Plan evaluation requires not only DVH analysis but it also include dose distribution analysis.

BIOPHYSICAL INDICES

Conformity index (CI)

- Conformity index was developed as an extension of section-by-section dosimetric analysis and DVH.
- Defined as an absolute value resulting from the relationship between tumor volume or a fraction of this volume and the volume delineated by an isodose or a fraction of this volume.
- It can also be defined by the ratio of an isodose with another isodose (prescription isodose, reference isodose, minimum isodose, maximum isodose).
- 1993- proposed by RTOG

  Described in ICRU Report 62

LOÏC FEUVRET, IJ ROBP64,(2)333–342, 2006

PHYSICAL INDICES

$$Quality\ of\ coverage_{RTOG} = \frac{I_{min}}{RI} \tag{1a}$$

where $I\ min$ = minimum isodose around the target, and RI = reference isodose.

$$Homogeneity\ index_{RTOG} = \frac{I_{\max}}{RI} \tag{1b}$$

where $I\ max$ = maximum isodose in the target, and RI = reference isodose.

$$Conformity\ Index_{RTOG} = \frac{V_{RI}}{TV} \tag{1c}$$

where V_{RI} = reference isodose volume, and TV = target volume.

Quality of coverage = I_{min}/RI

- if the 90% isodose covers all of the clinical and pathologic target volume - comply with the protocol
- 80% isodose covers all of the clinical and pathologic target volume - minor protocol violation
- 80% isodose does not cover all of the clinical and pathologic target volume - major protocol violation

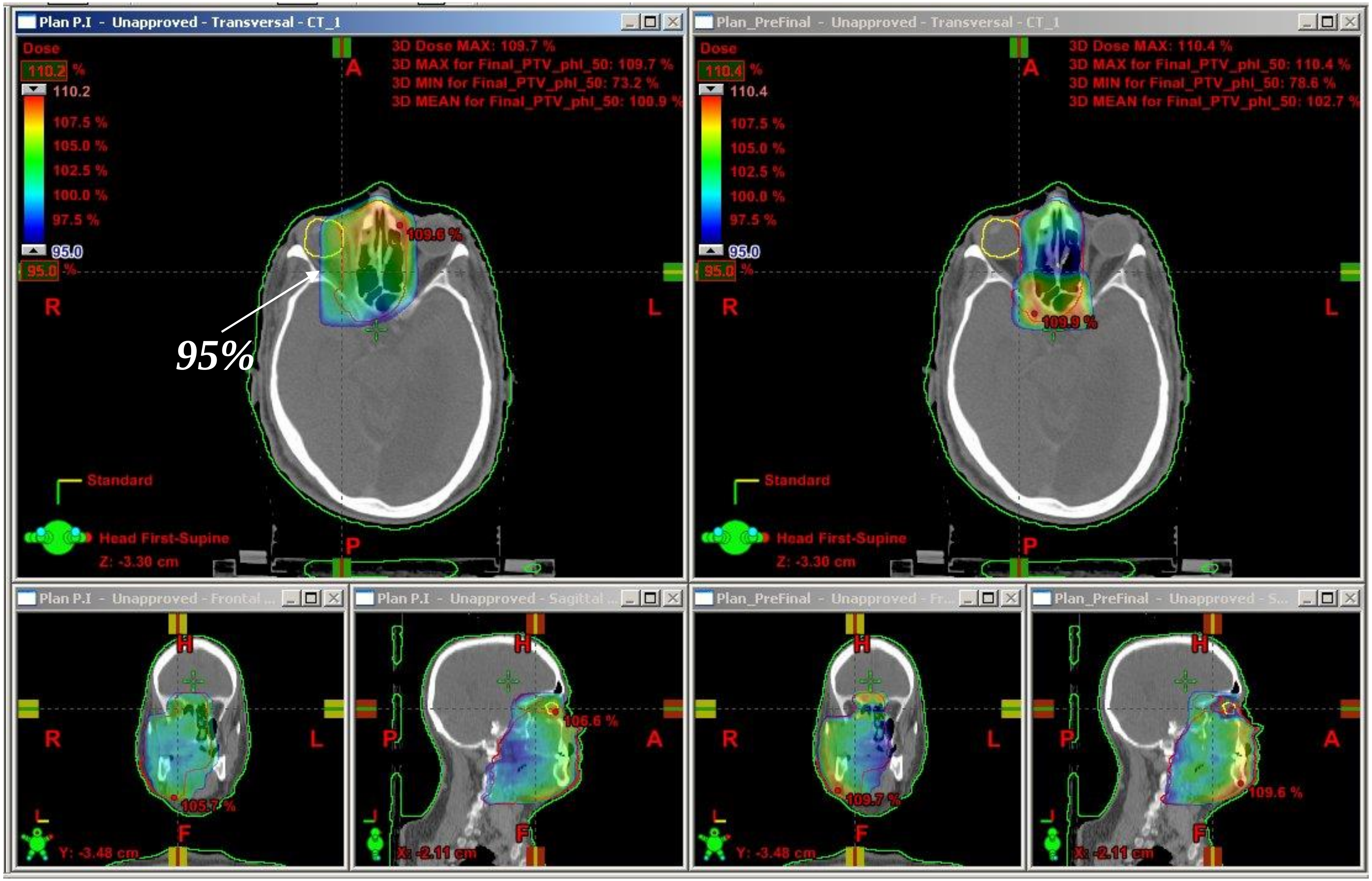
- Homogeneity index = I_{max}/RI
  - < = 2 - comply with the protocol
  - 2 to 2.5 - minor protocol violation
  - > 2.5 - major protocol violation is considered to be

- Conformity Index = V_{RI}/TV
  - Conformity index =1 corresponds to ideal conformation
  - >1 - Irradiated volume is greater than the target volume and includes healthy tissues
  - <1- Target volume is only partially irradiated.
  - Conformity index 1- 2 - comply with the treatment plan
  - 2 - 2.5 & 0.9 – 1- minor violation
  - <0.9 & >2.5 - major violation

Dosimetric index	Definition	Reference
Coverage	Quality of coverage = Imin/RI	RTOG[8]
	Coverage, % = $(TV_{PIV}/TV) \times 100$	ICRU 62[8,9]
Homogeneity	HI_{RTOG} = Imax/RI	RTOG[8]
	$HI_{ICRU} = (D_{2\%}-D_{98\%})/D_{50\%}$	ICRU 83[10]
	CI_{RTOG} = PIV/TV $CN = (TV_{RI}/TV) \times (TV_{RI}/V_{RI})$	RTOG[8] Van't Riet et al[11]
	$CI_{Paddick} = (TV_{PIV}{}^2/TV \times PIV)$	Paddick[12], ICRU 91[14]
Conformity indices	$CI_{geometric}$ (g) = LUF + HTOF	SALT[8]
	$CGI_c = 100 \times TV/PIV$	Wagner et al[15]
	$CI = (TV_{PIV}/PIV)$	Lomax and Scheib[16]
	$R_{50\%} = (PIV_{50\%PIV})/PTV$	RTOG 0915
Gradient	Gradient index = $(PIV_{50\%PIV}/PIV)$	Paddick and Lippitz[17]
	Gradient (cm) = $(R_{eff,50\%RX} - R_{eff,RX})$	Wagner et al[15]
	$Gradient_{eff} = 50\,\%/(R_{eff,50\%RX} - R_{eff,RX})$	Mayo et al[18]

CI, conformity index; CN, confirmation number; $D_{x\%}$, minimal dose to the x% highest irradiated target volume; $gradient_{eff}$, effective gradient. (Note: in our study, Prescription isodose = reference isodose = 100%); HI, homogeneity index; HTOF, healthy tissue overdosage factor (HTV_{RI}/TV); HTV_{RI}, healthy tissue volume covered by the reference isodose; I_{max}, maximum isodose in the target; I_{min}, minimal isodose surrounding the target; LUF, lesion underdosage factor ($TV_{<RI}/TV$); PIV, prescription isodose volume; PTV, planning target volume; $R_{eff,\ RX}$, $R_{eff,\ 50\%RX}$ = effective radii of 100 and 50% isodoses (R_{eff}); RI, reference isodose; $TV_{<RI}$ = target volume receiving less than reference dose; V_{RI}, volume of reference isodose .

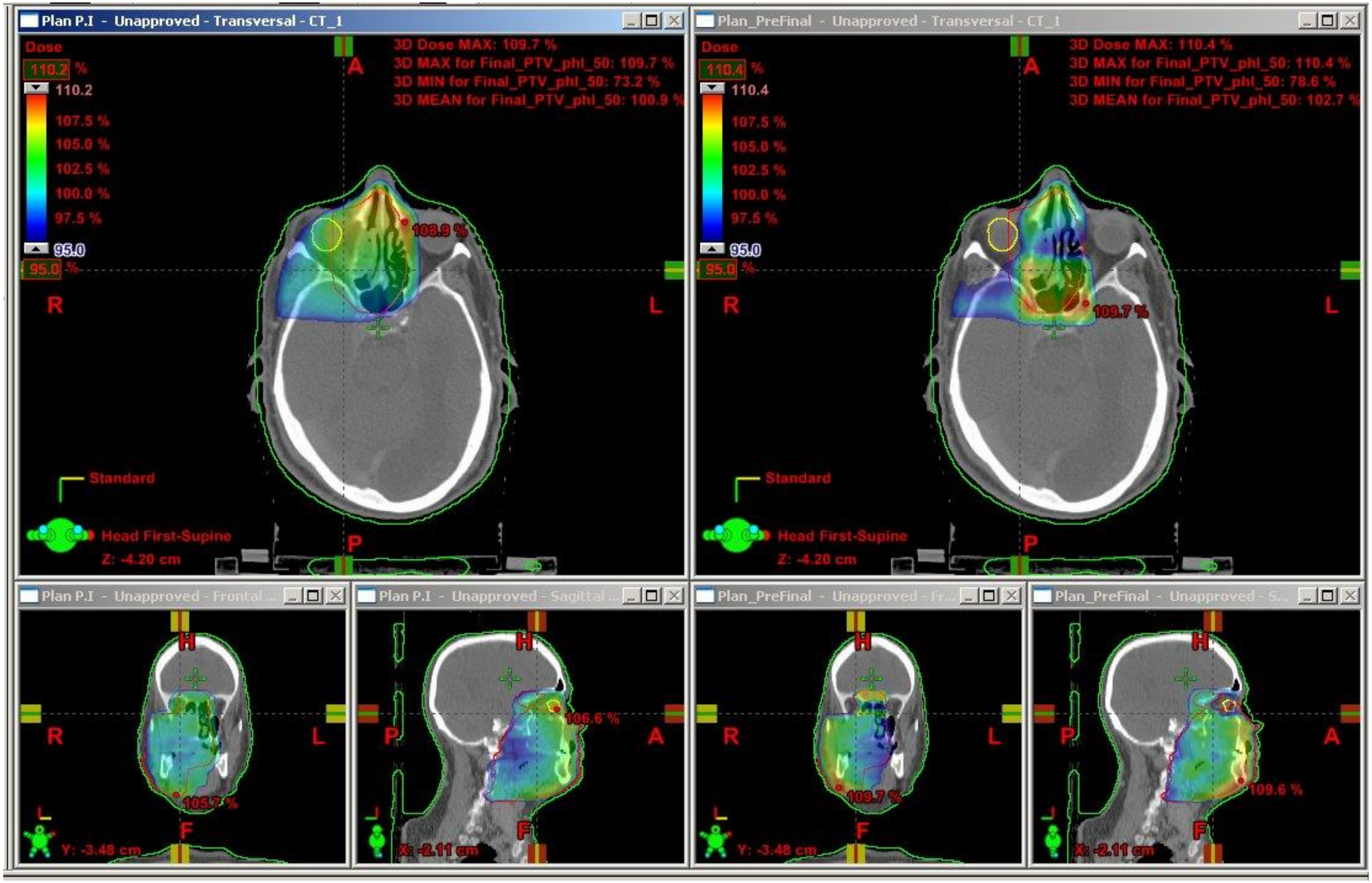
Plan Evaluation: Example



Plan1

Plan2

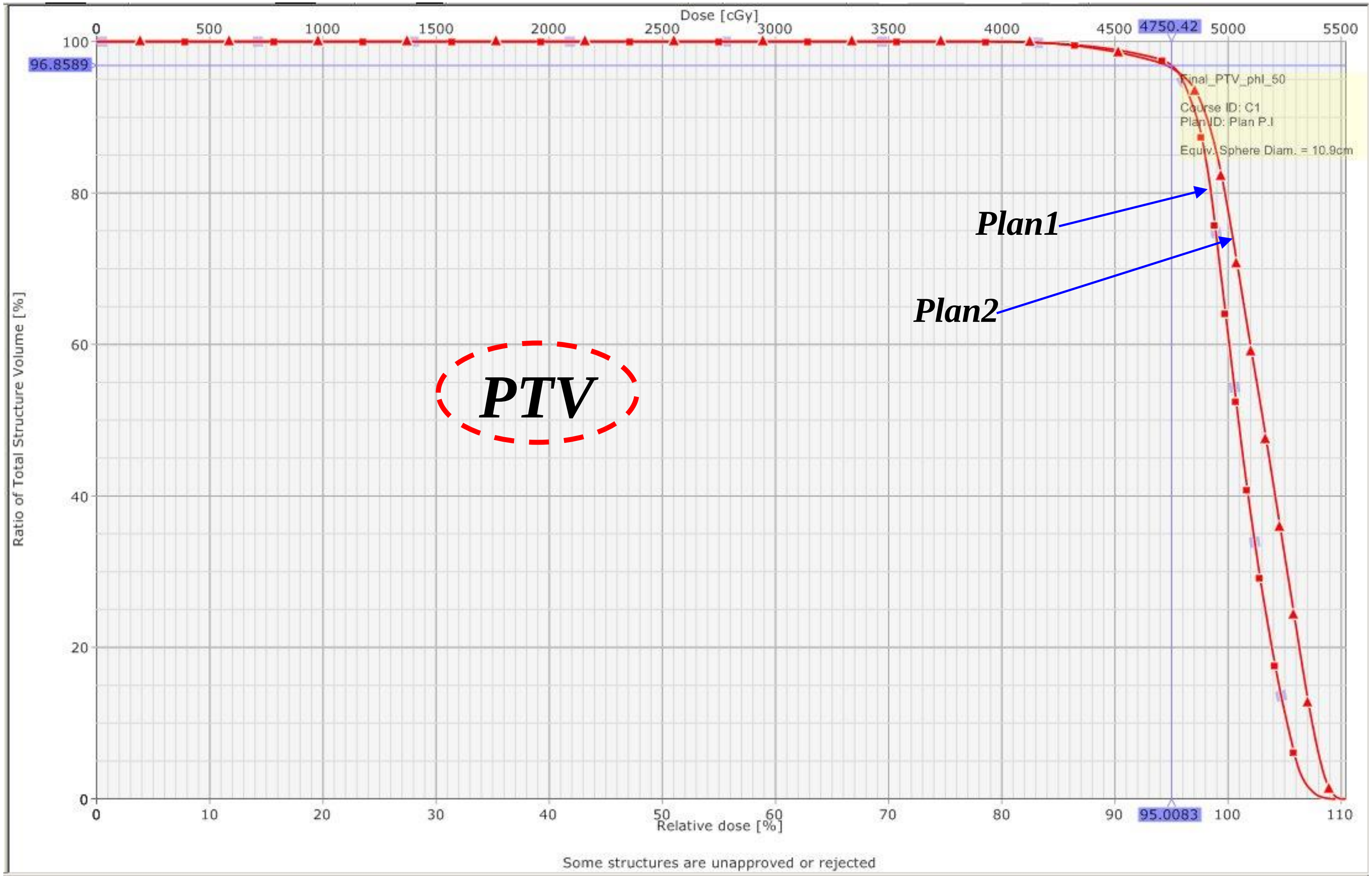
Plan Evaluation: Example



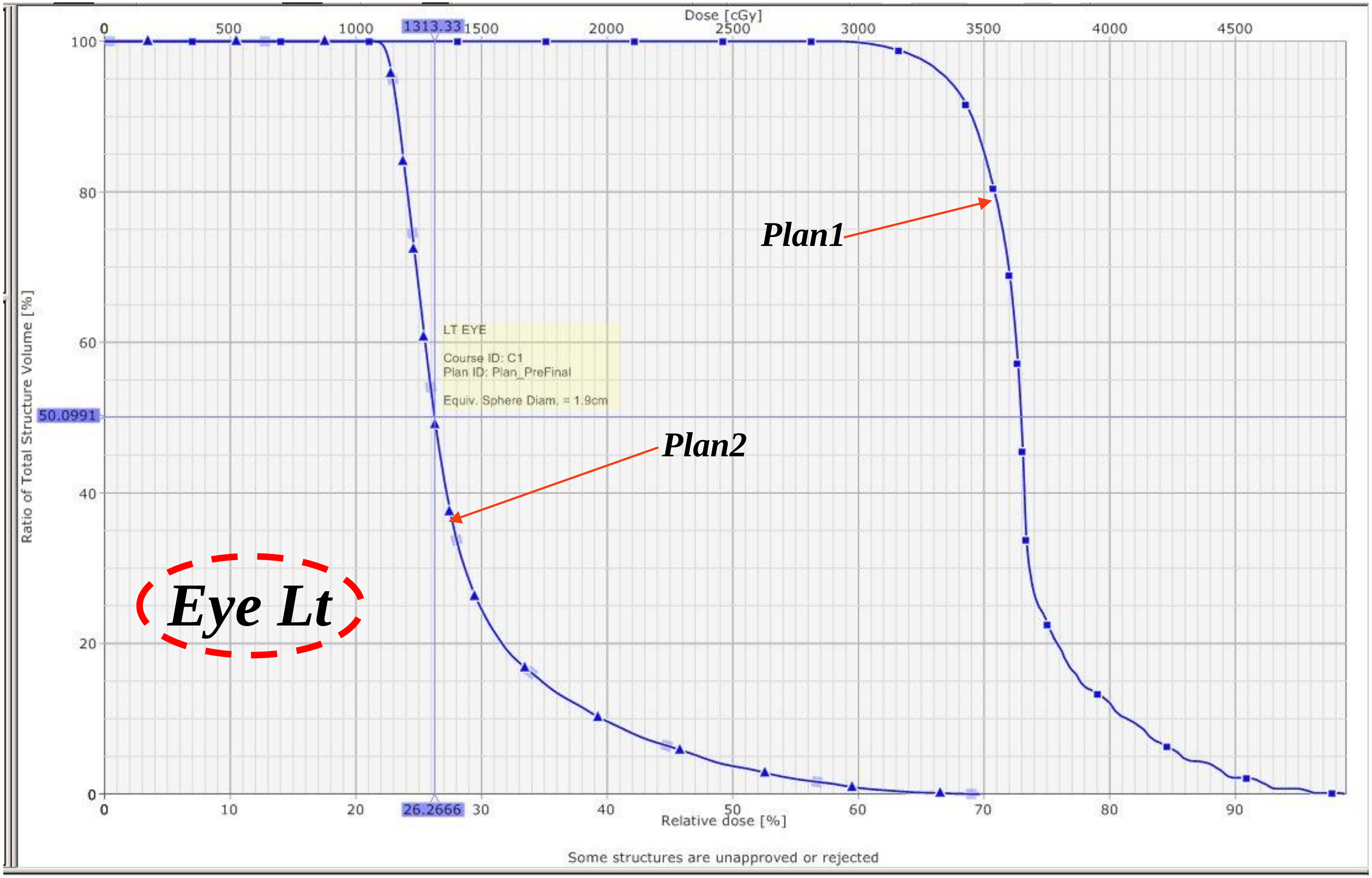
Plan1

Plan2

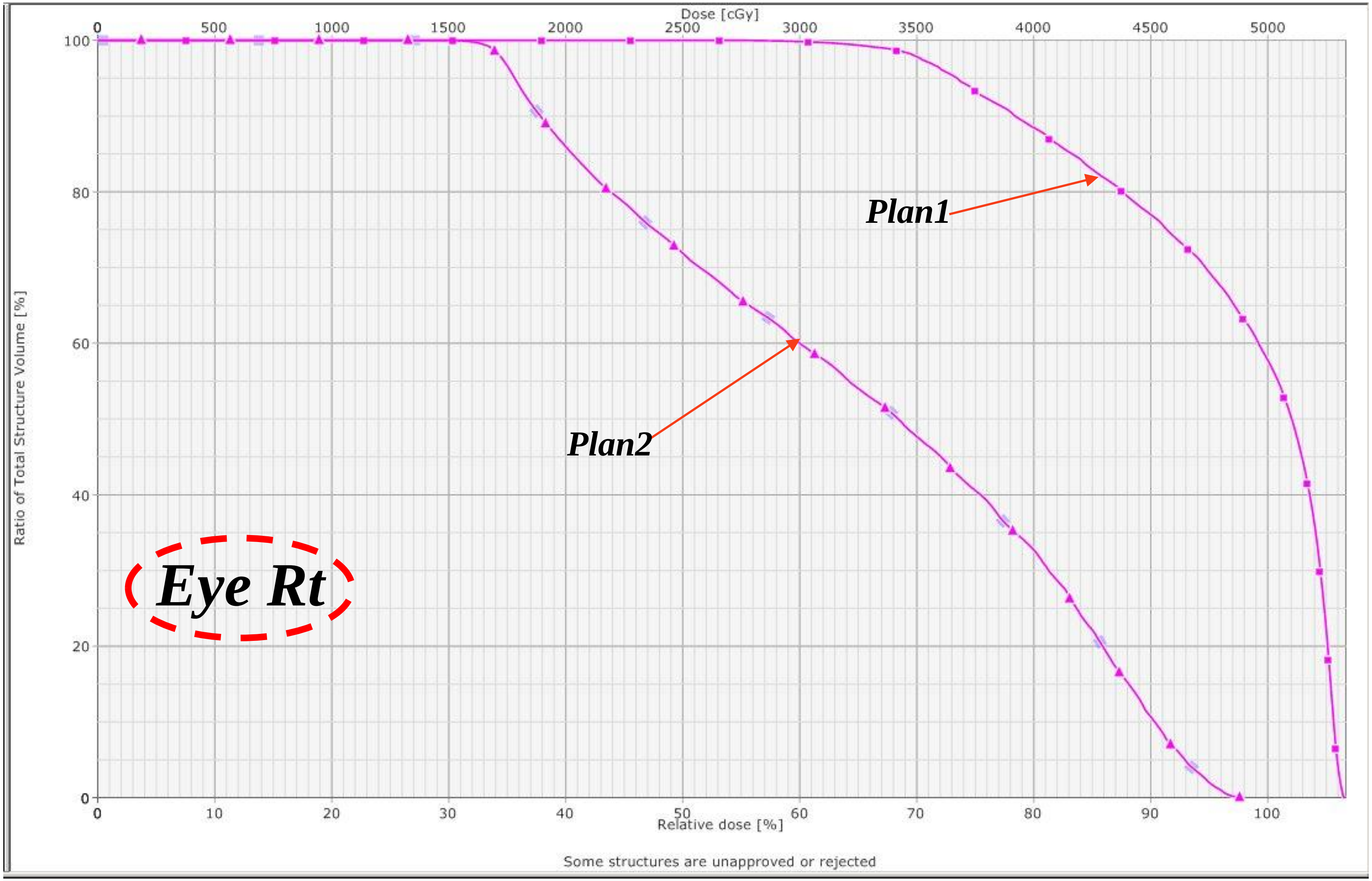
Plan Evaluation: Example



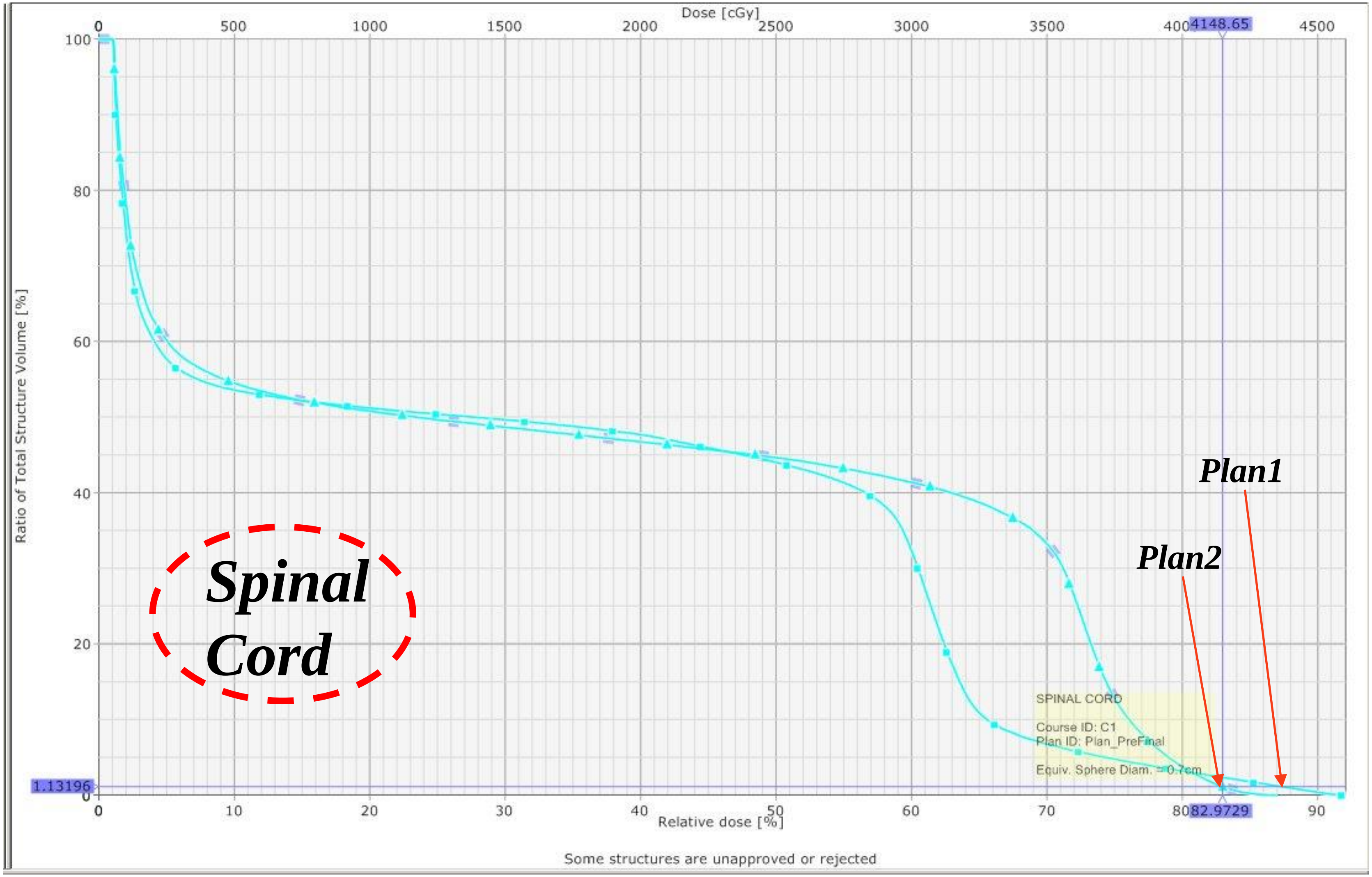
Plan Evaluation: Example



Plan Evaluation: Example



Plan Evaluation: Example



QUALITY ASSURANCE

Quality assurance (QA)

- 'Quality assurance' is all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy the given requirements for quality.
- All relevant procedures, activities and actions, and hence all groups of staff involved in the process under consideration.

PATIENT SPECIFIC QA

- Need of IMRT QA
- IMRT QA Tools
- Analysis

Why do we need IMRT QA?

3DCRT

- Field design based on BEV
- Low dose gradient
- Manual MU verification
- Portal images to validate OAR avoidance

IMRT

- Dose distribution complexity
- Dynamic beam delivery
- High dose gradient
- Non uniform fluence
- Spatial location of dose gradient

Uncertainties in IMRT Delivery System

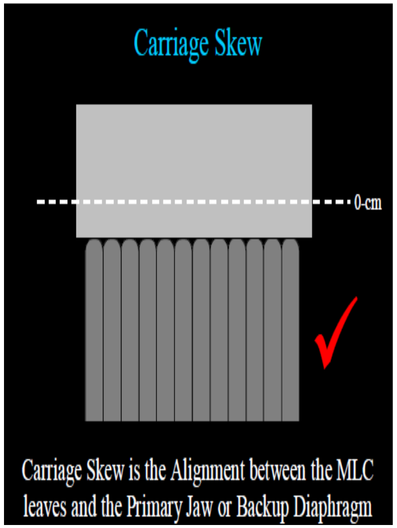
- MLC leaf positions

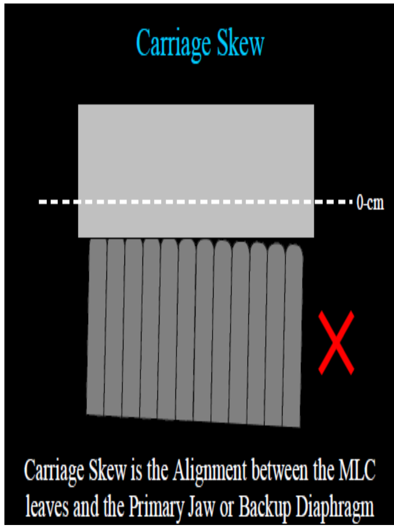
  Sweeping field (weekly)

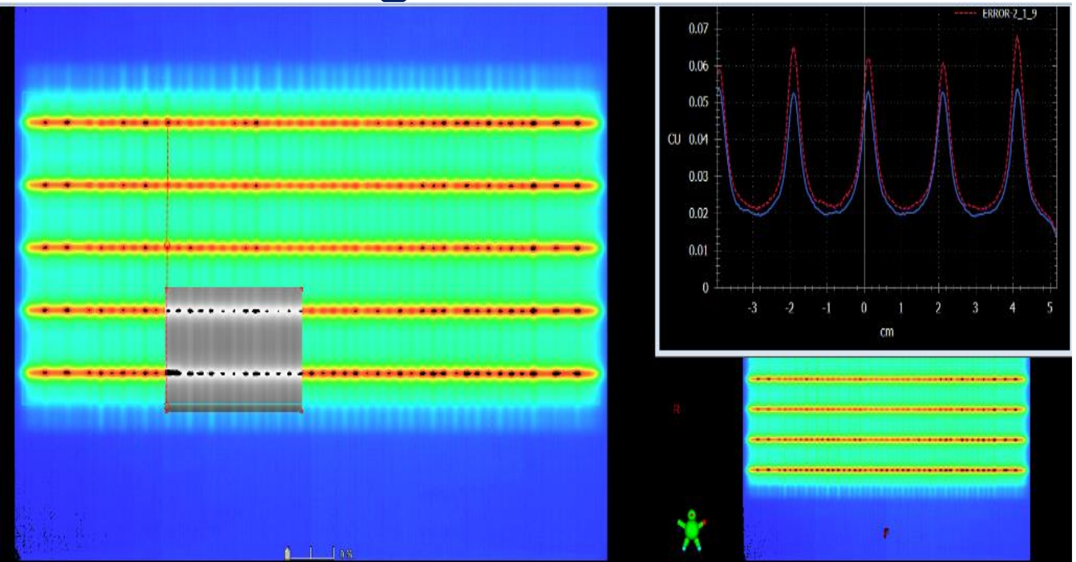
  Garden fence test (weekly)

  Dosimetric leaf gap (quarterly QA)

  MLC allignment







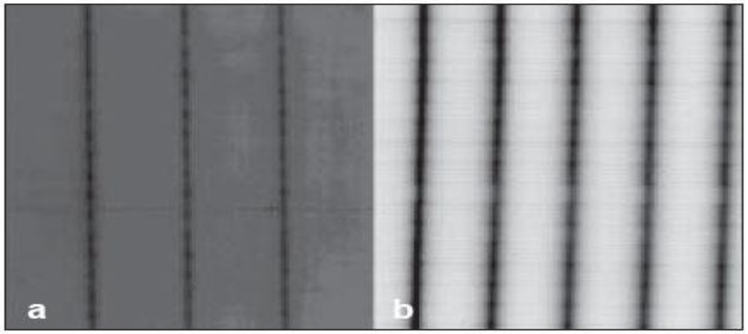


Figure 1: (a) Picket fence test (b) Garden fence test, shows the stability and reproducibility of leaf gap between MLC leaves in dMLC mode

Pre treatment QA

- Dosimetric tasks that are performed prior to the treatment of each patient.
- Parameters from the patient plan are applied to an IMRT phantom
- Phantom is alligned with lasers and irradiated with patient specific QA plan.
- The measured and calculated dose distributions are compared with the aid of software
- To facilitate the safe clinical implementation of IMRT

Patient Specific DQA

IMRT QA Tools. . . .

- Point dosimeters(1-D)

Ionization chambers

Solid state dosimeters.

(TLD/MOSFET IN VIVODOSIMETRY)

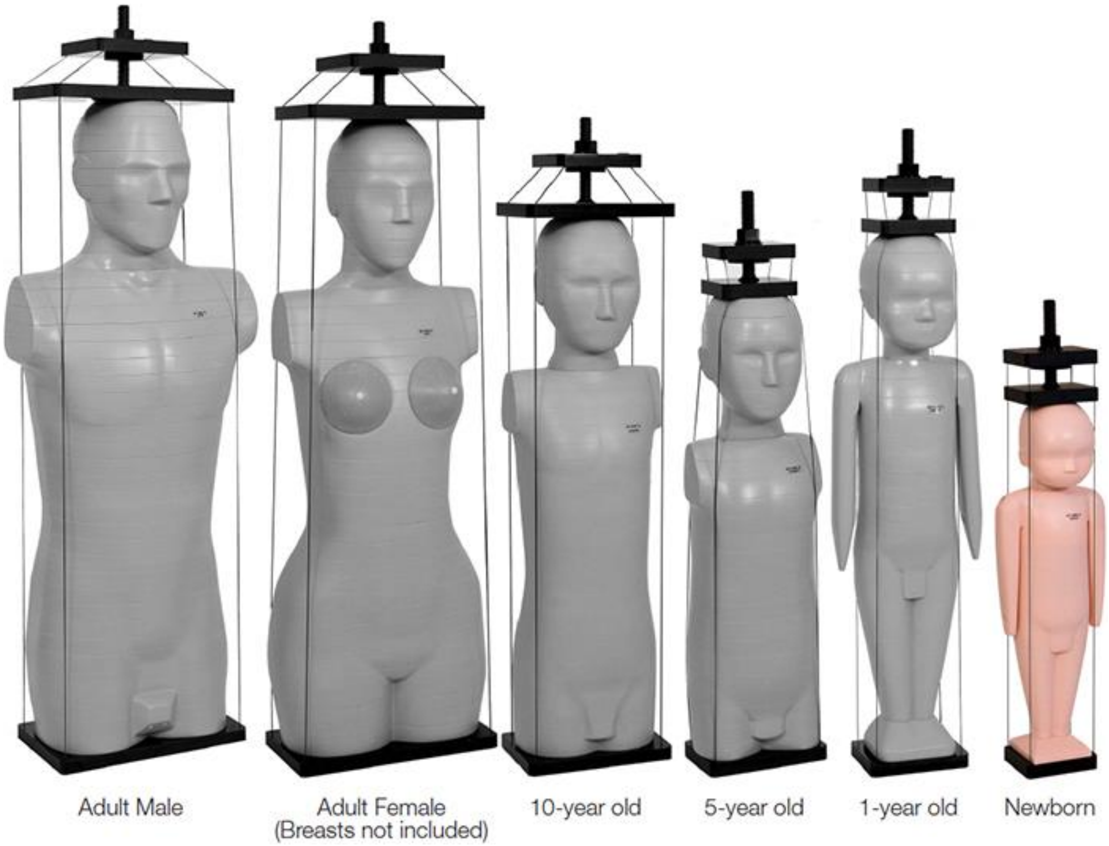
- Two-dimensional dosimetry

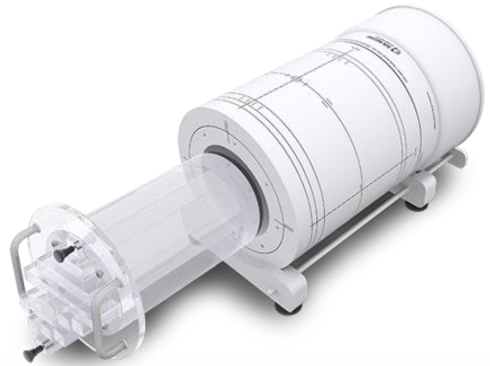
Film **(RADIOCHROMIC/GRAPHIC)**

EPIDS

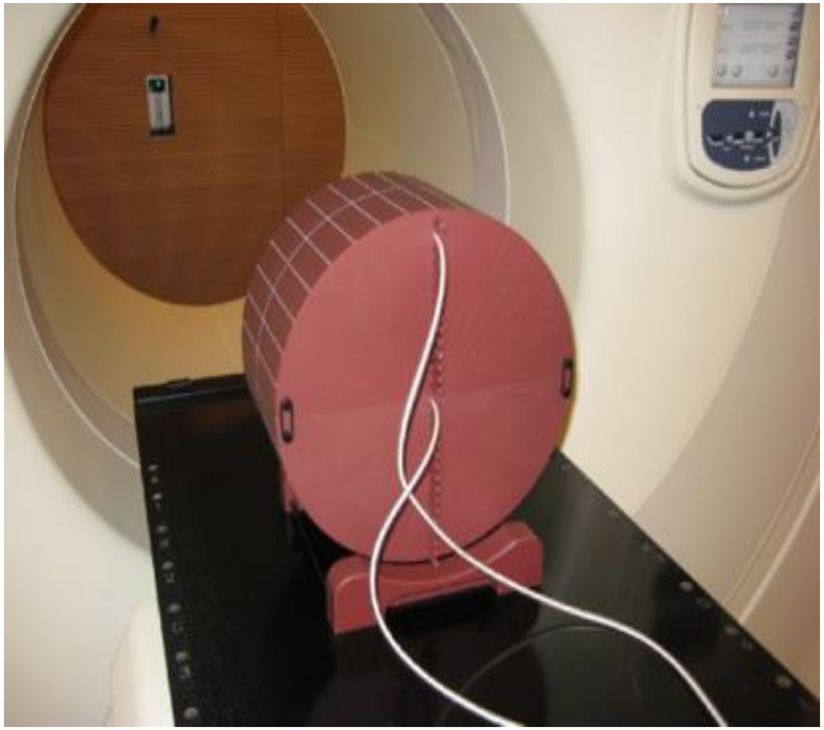
Array detectors. .

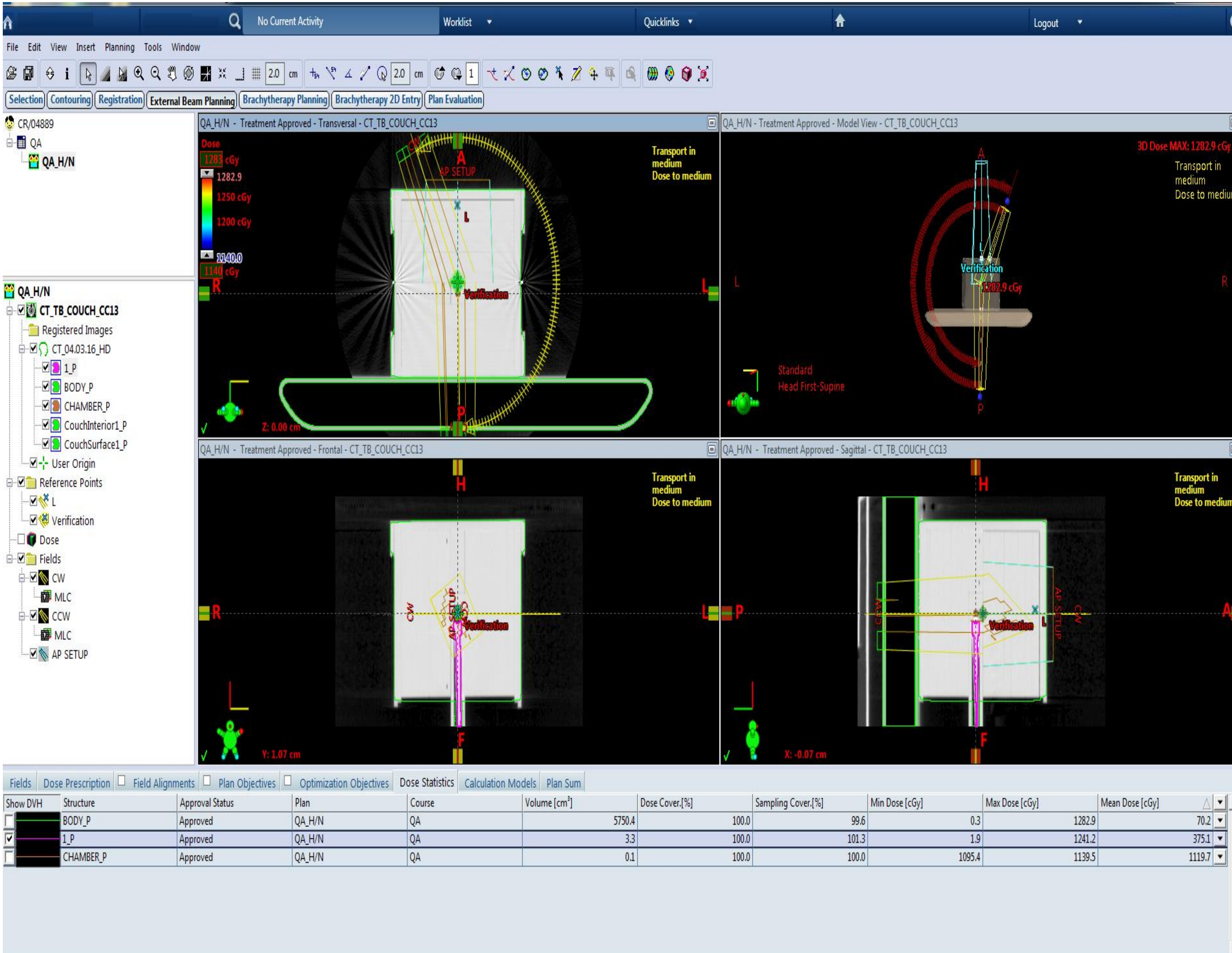
Quality assurance & control





Patient Specific DQA





Show DVH	Structure	Approval Status	Plan	Course	Volume [cm³]	Dose Cover.[%]	Sampling Cover.[%]	Min Dose [cGy]	Max Dose [cGy]	Mean Dose [cGy]
☐	BODY_P	Approved	QA_H/N	QA	5750.4	100.0	99.6	0.3	1282.9	70.2
☑	1_P	Approved	QA_H/N	QA	3.3	100.0	101.3	1.9	1241.2	375.1
☐	CHAMBER_P	Approved	QA_H/N	QA	0.1	100.0	100.0	1095.4	1139.5	1119.7

Point dosimetry

ion chambers

- Advantages...
- Available in different shape and sizes
- Dosimetric response is well understood.
- Absolute dose measurements –can be used as a benchmark standard
- Easy to calibrate

- Disadvantages..
- Only one measurement point for each irradiation
- Volume averaging effect
- Significant errors if placed to high dose gradient regions

TLDs

Advantages

- Multiple measurement points in a single irradiation
- Reusable
- Easy to use in multiple phantoms
- Small size and versatility in placement
- Readily available readout equipment
- Achievable accuracy: 2-3%

Disadvantages

- Requires calibration to determine calibration factor for each TLD chip
- TLD reader response and oven temperature should me routinely monitored to maintain consistent TLD response
- large number of TLDs required for verification in a plane
- inefficient for routine IMRT QA

Radiographic Film

Advantages

- Readily available (XV, EDR2, …)
- Can be cut into any desired shape
- Excellent spatial resolution (<1mm)
- Less expensive than other 2-D systems

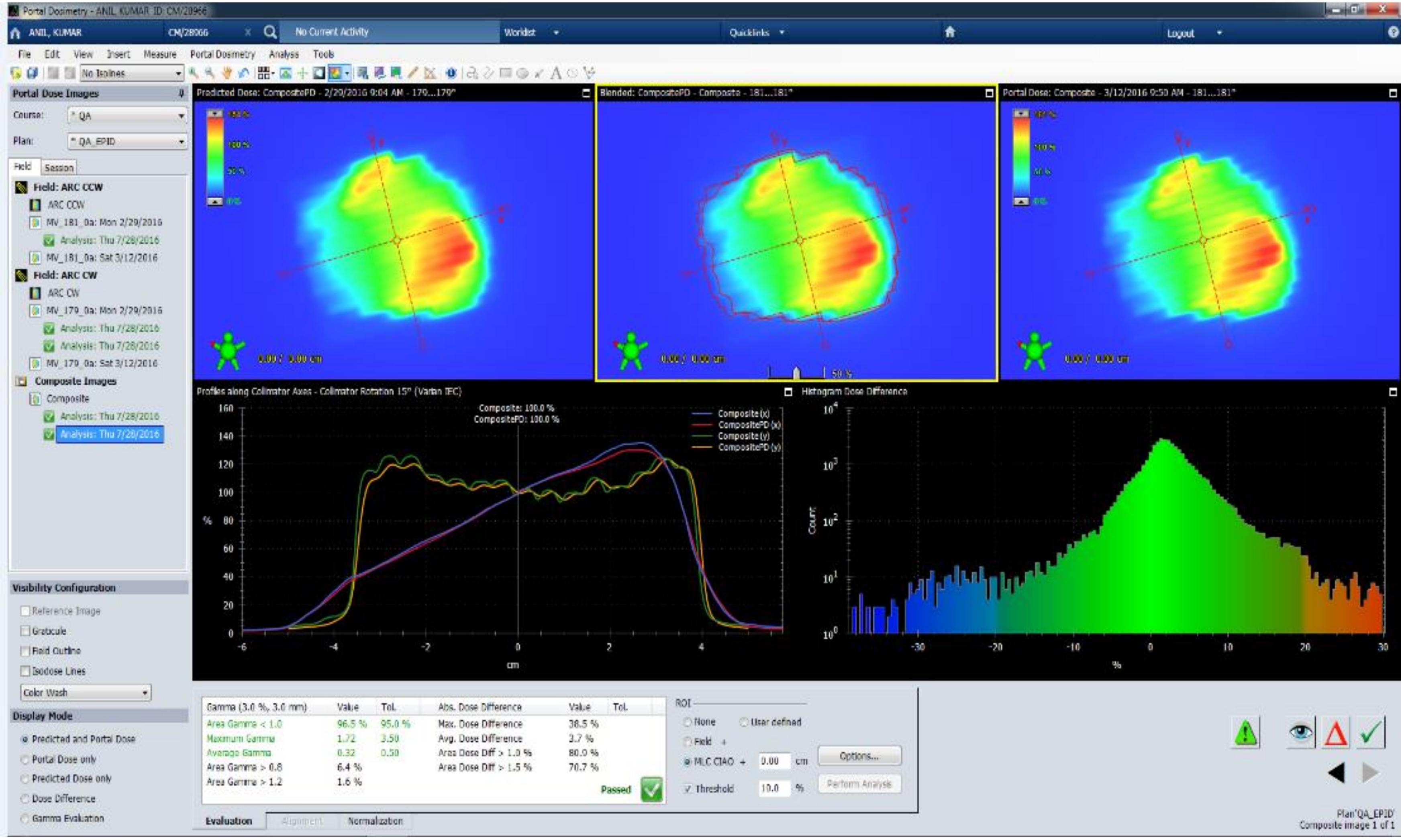
Disadvantages

- Dependent on QA of film batch
- Dependent on processor and digitizer
- Sensitive to storage conditions
- Need to measure the response to dose for each experiment

EPIDS..

- Exposing treatment plan directly into EPID in absence of patient/phantom
- Mounted to LA
- Easy to perform
- Imager response must be calibrated to a standard

EPID portal dosimetry



Dosimetric Analysis Tools

- % Variation (point dose)
- 2-D dose difference displays with colorwash
- Dose difference histograms
  (Low dose gradient regions)
- Distance-to-agreement (DTA)
  high dose gradient regions
- Gamma evaluation (3% , 3 mm)

Radiotherapy treatment verification

Types of verification

- Offline treatment verification
- Online treatment verification
- Inter-fractional treatment verification

Offline

- Margin requirements are dominantly determined by systematic errors and much less by random errors.
- Aim to correct for the mean error of a patient without correcting daily variation.
- Margin reduction with limited workload.
- Based on biological modeling and physical considerations,the optimal number of imaging days in offline correction protocols was considered to be 10% of all fraction

Online

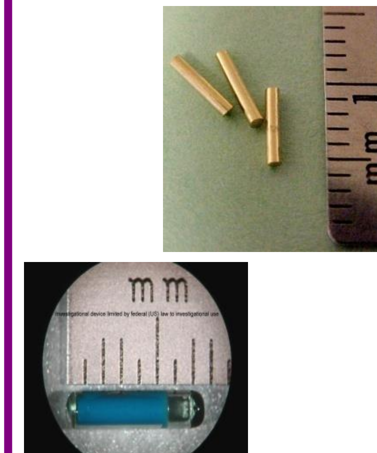
- Workload of measurement and correction is reducing.
- Advantage – both systematic and random errors are corrected efficiently.
- Disadvantage- analysis and corrections must be fast, simple,and unambiguous, whereas the time pressure could affect the accuracy of the procedure.

IGRT TECHNOLOGIES

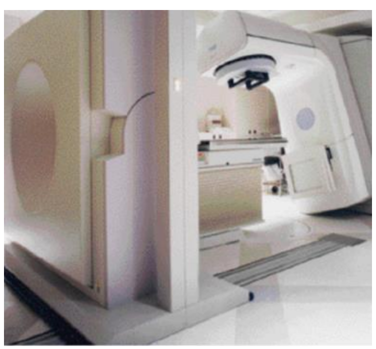
Ultrasound

kV Radiographic Cyber Knife

Portal Imaging



Markers



Siemens PRIMATOM™

TomoTherapy Hi-Art™

Elekta Synergy

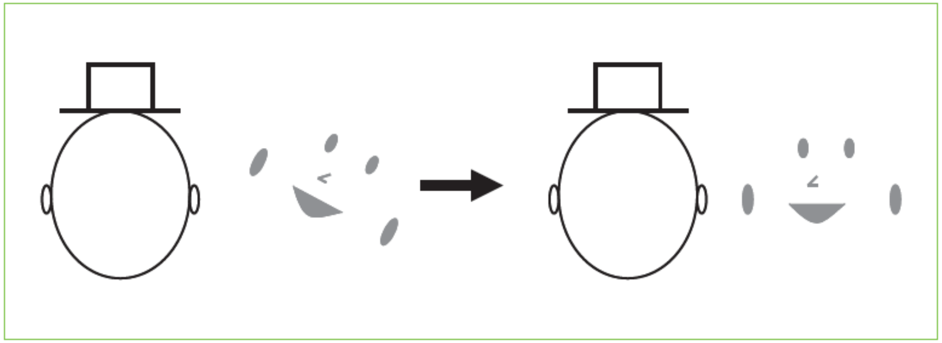
Varian OBI™

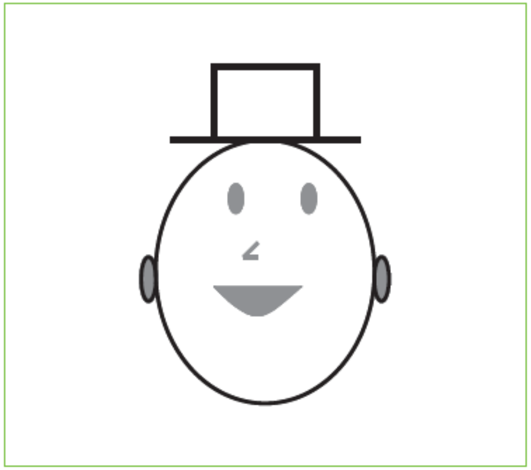
Image registration

- Measurement of setup error and organ motion
- **Rigid registration** of the entire scanned portion of the patient.

Disadvantages

- anatomic deformation will invariably lead to poor registration.
- **Deformable registration**





Two-dimensional imaging

- Every radiograph provides localisation data in two dimensions (2D).
- Usually, skeletal anatomy on the verification image, which is compared with reconstructed reference radiographs(DRR) derived from the planning CT scan.
- Estimation of setup errors in three dimensions (3D) is possible with two or more radiographic comparisons

Electronic Portal Imaging Device (EPID) (Megavoltage imaging)

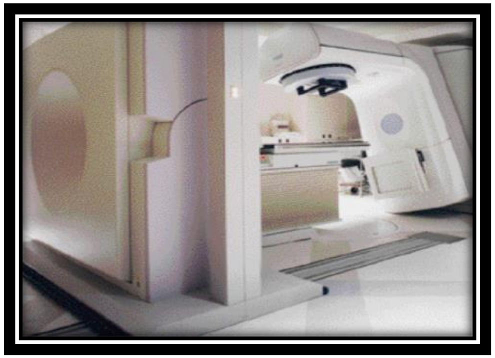
Portal vision Varian

iView GT Electa

CT Based Imaging

- KVCT (80- 150 kVp)

Fan beam CT



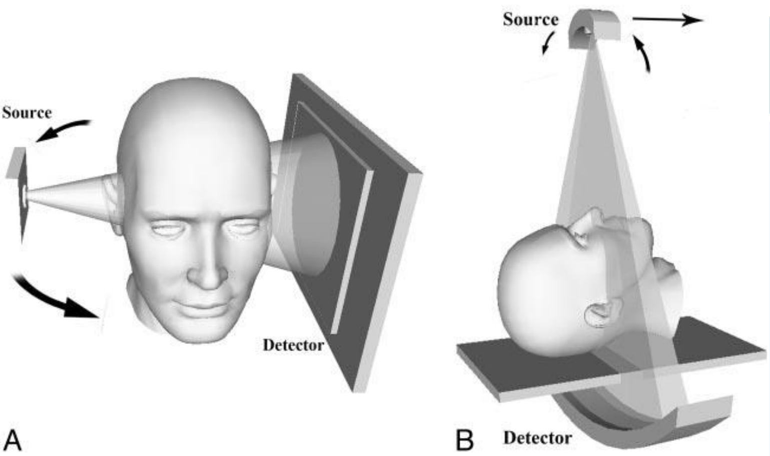
Cone beam CT

MVCT (2-6 MV)

Fan beam CT

Cone beam CT

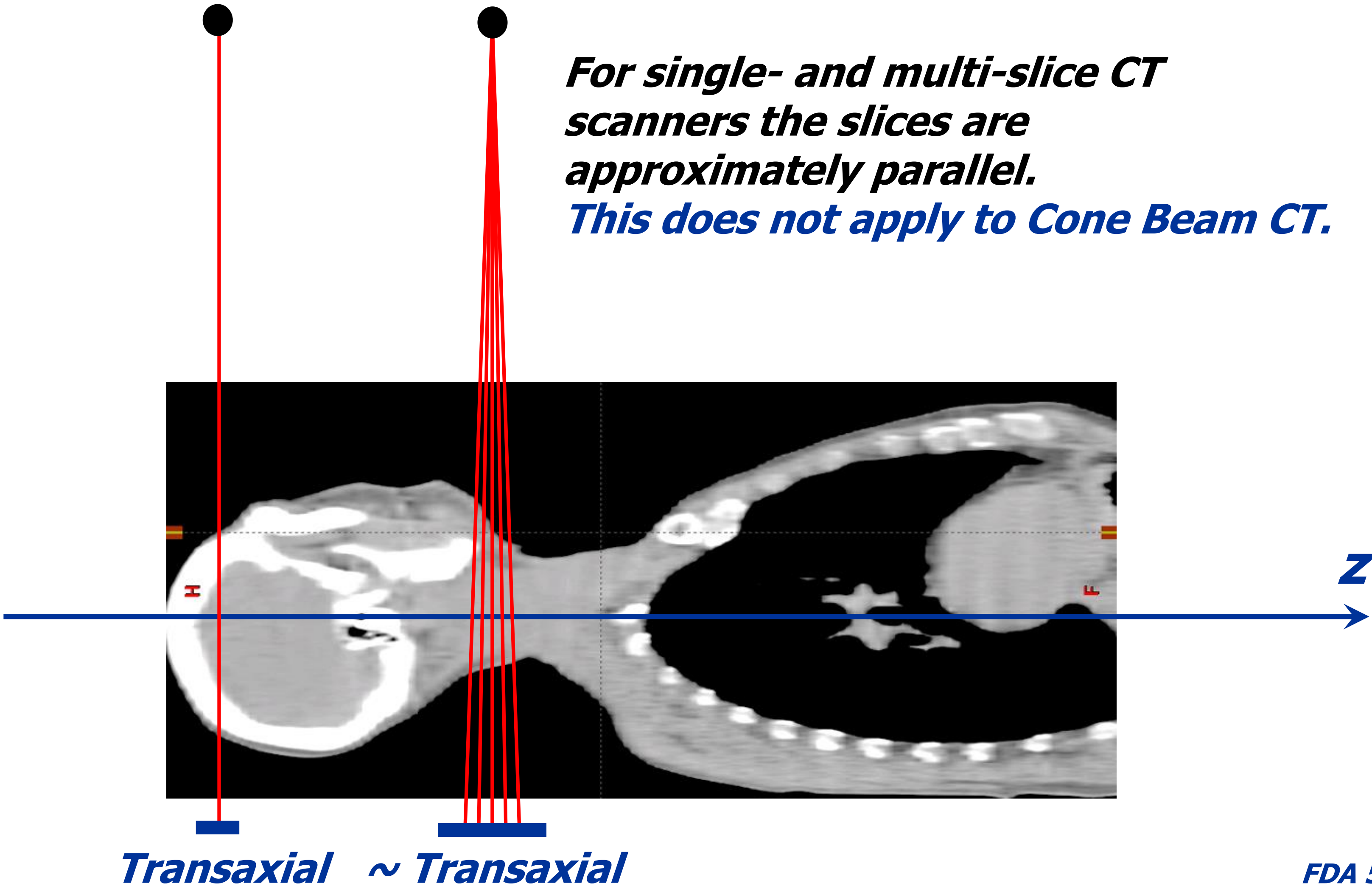
Cone beam VS Fan beam



cone beam	Fan beam
forms a conical geometry between the source (apex) and the detector (base)	Collimator restricts the x-ray beam to approximately 2D geometry.
entire volumetric dataset can be acquired with a single rotation of the gantry	data acquisition requires both rotation and z-direction translation of the gantry

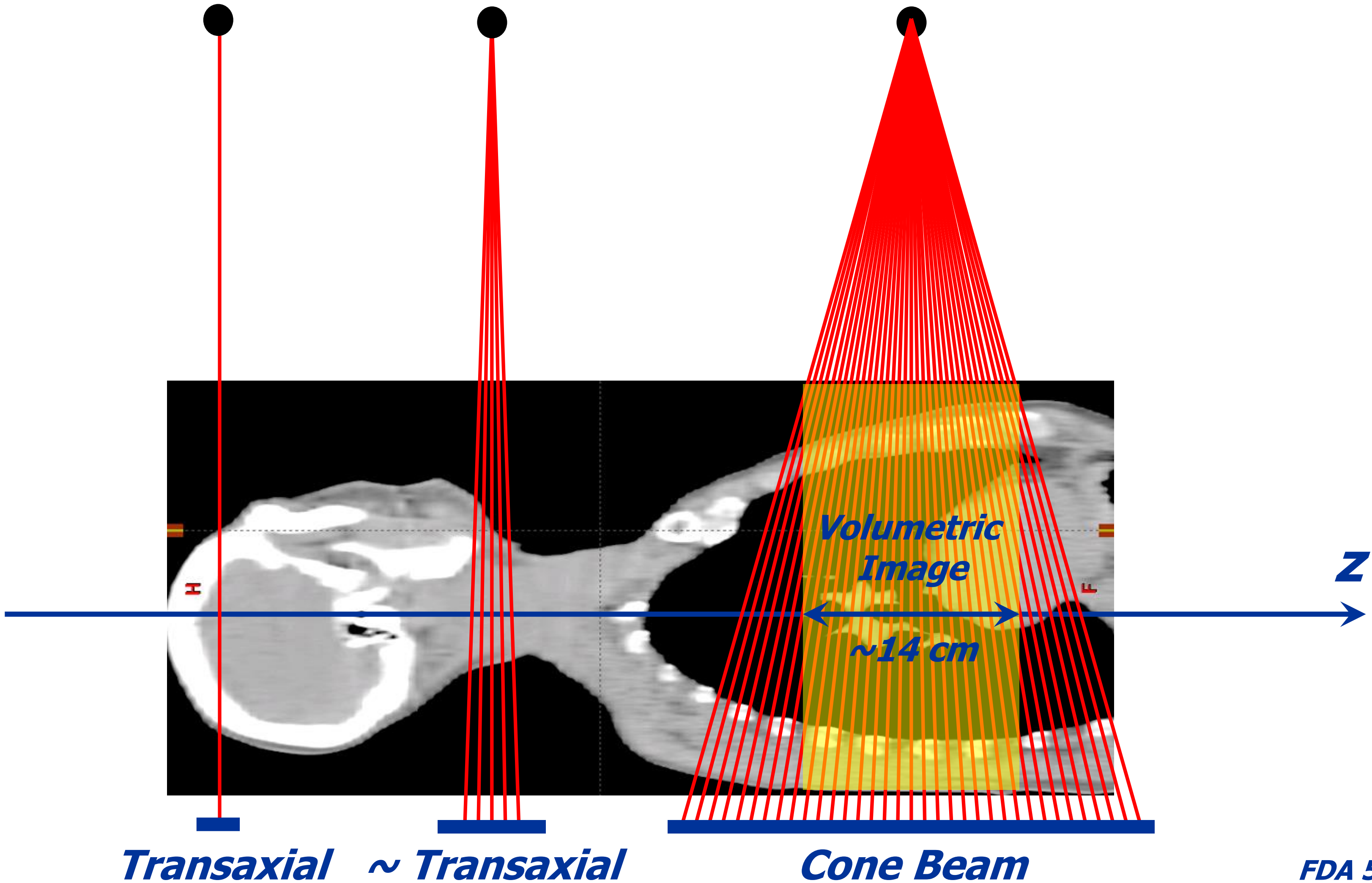
Cone Beam CT Mode – Axial (z) Geometry

For single- and multi-slice CT scanners the slices are approximately parallel.
This does not apply to Cone Beam CT.



FDA 510(k)

Cone Beam CT Mode – Axial (z) Geometry

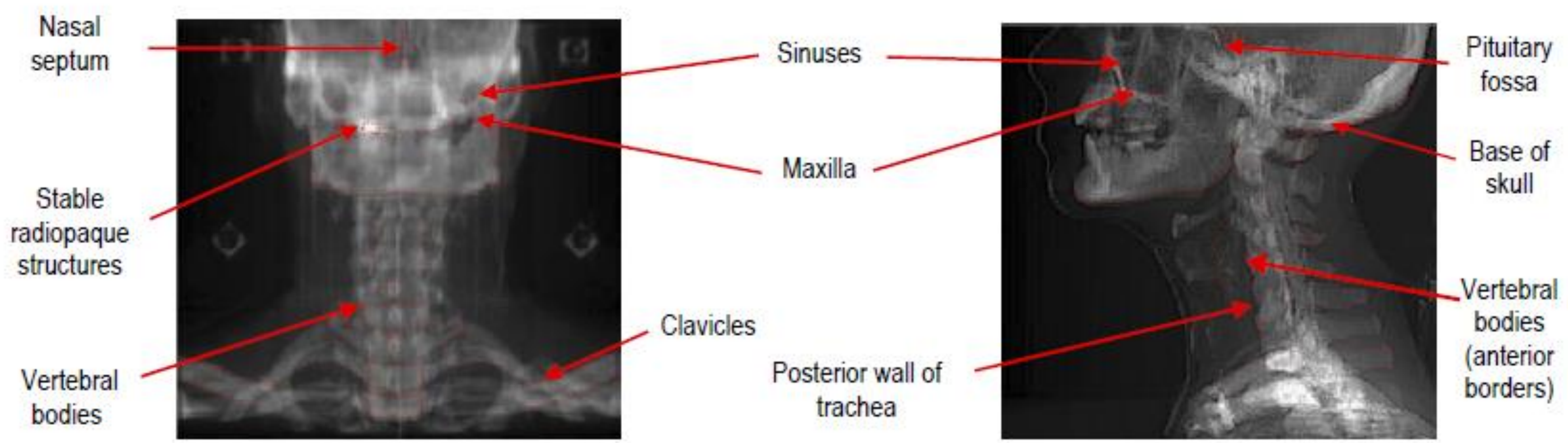


FDA 510(k)

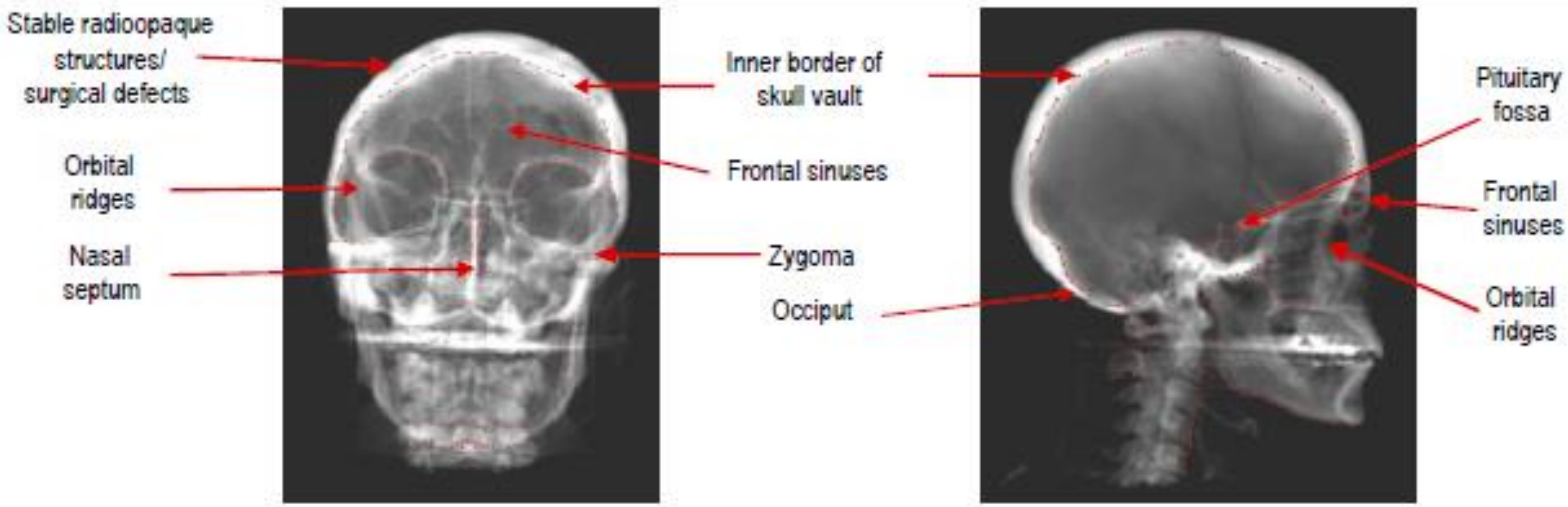
Advantages of KV over MV CT

- Offers higher contrast than MV imaging (due to the more pronounced photoelectric absorption)
- Greater visibility of bones or implanted markers
- Simplified interpretation of images
- Scanning time is less than MVCT
- Lower imaging dose

Set up verification
Bony structures in head and neck region



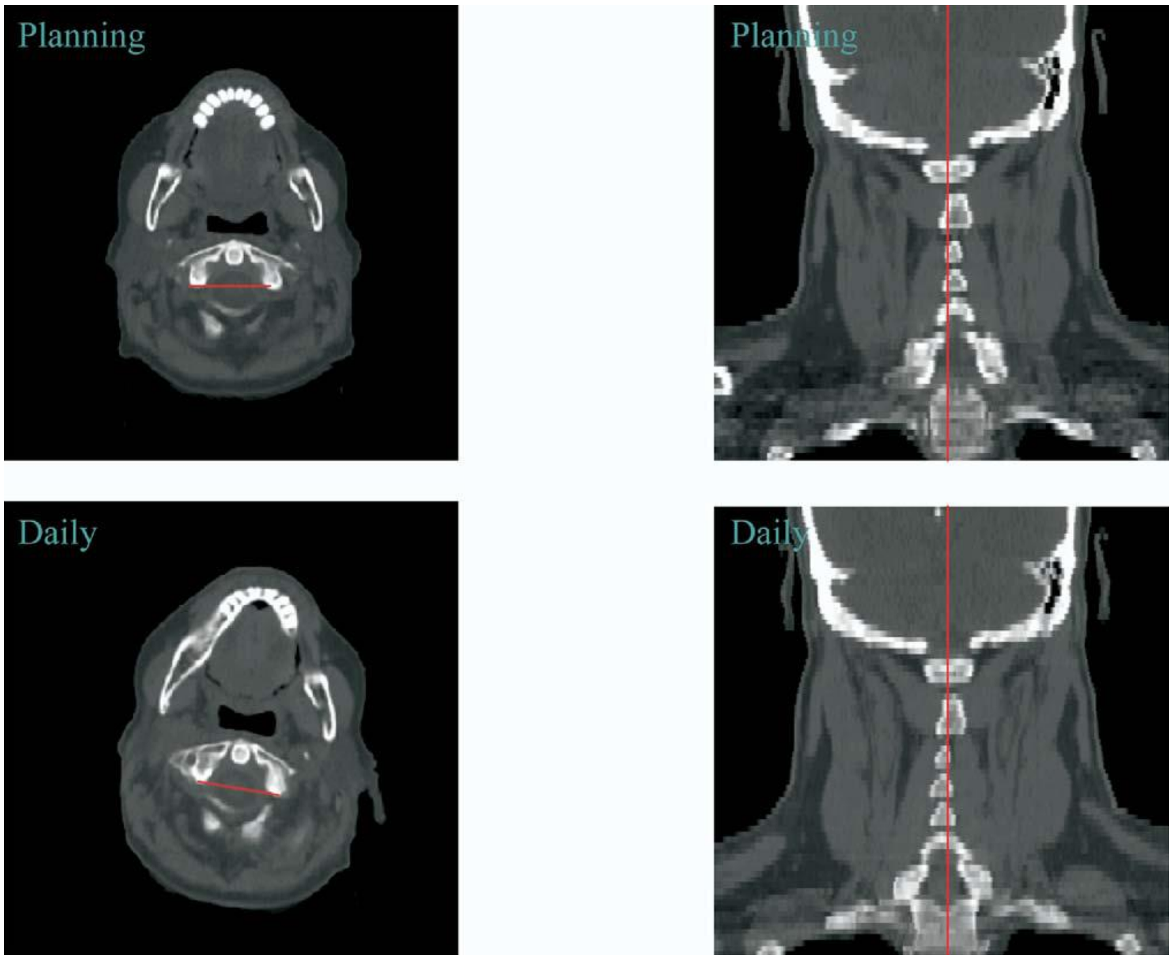
Brain

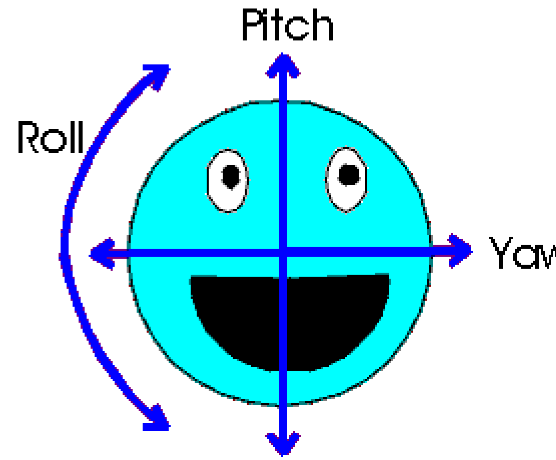

Stable radioopaque structures/ surgical defects
Orbital ridges
Nasal septum
Inner border of skull vault
Frontal sinuses
Zygoma
Occiput
Pituitary fossa
Frontal sinuses
Orbital ridges

Other Factors in Volume Alignment

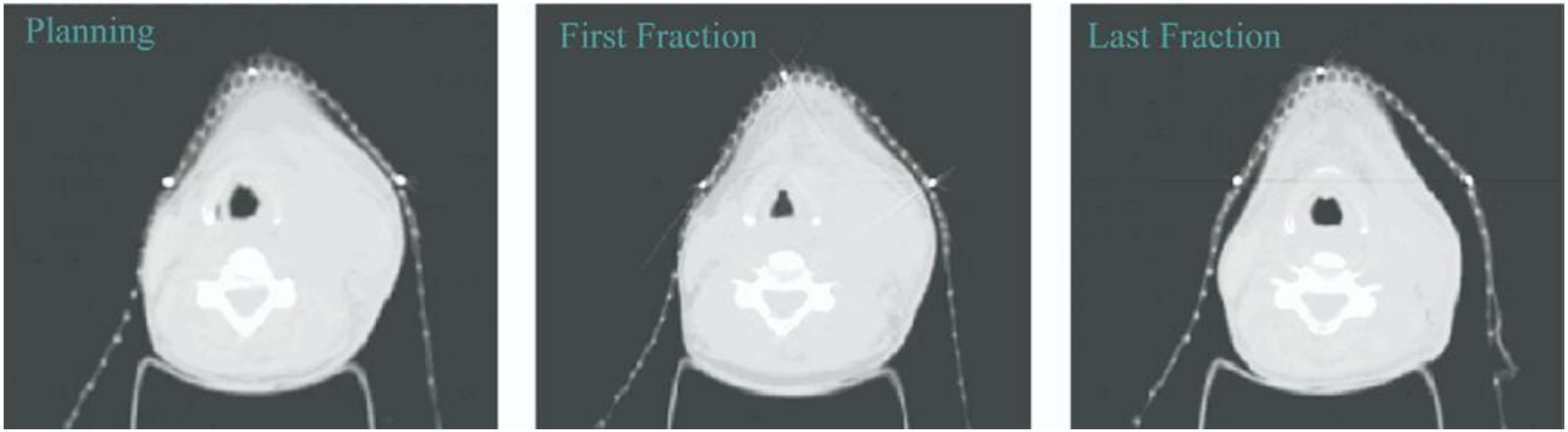
- Correction for rotations
- Deformation
- Intra-fractional organ motion

Rotational errors





Organ deformation



An example of increasing room inside a thermoplastic face mask because of tumour shrinkage as treatment progresses. Near the end of treatment, the lower neck was not centered on the headrest, presumably because of the patient's self-adjustment to the relatively "roomier" mask.

Offline Review

Icon	Status
	New
	Reviewed
	Approved
	Action required
	Disposed

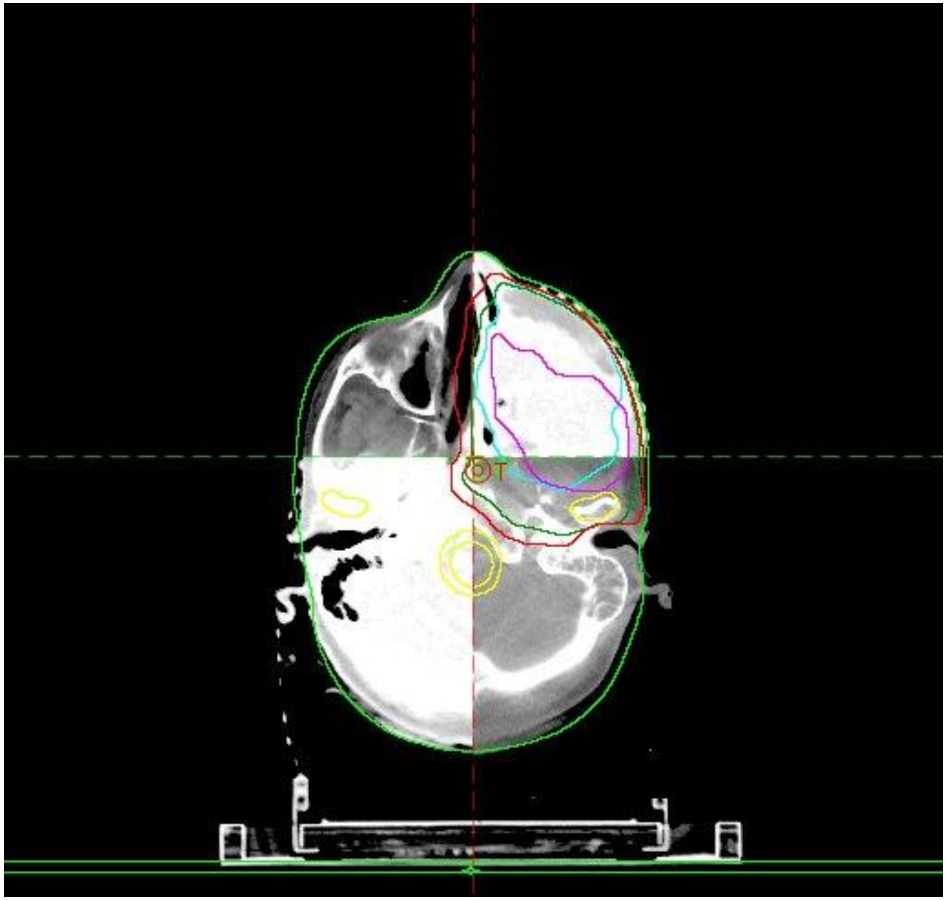
Matching tools

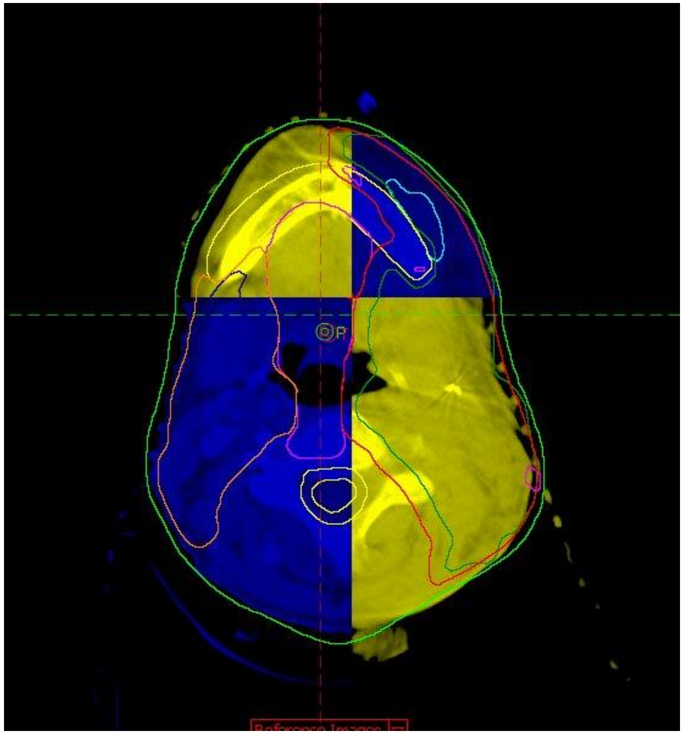
1)Split window

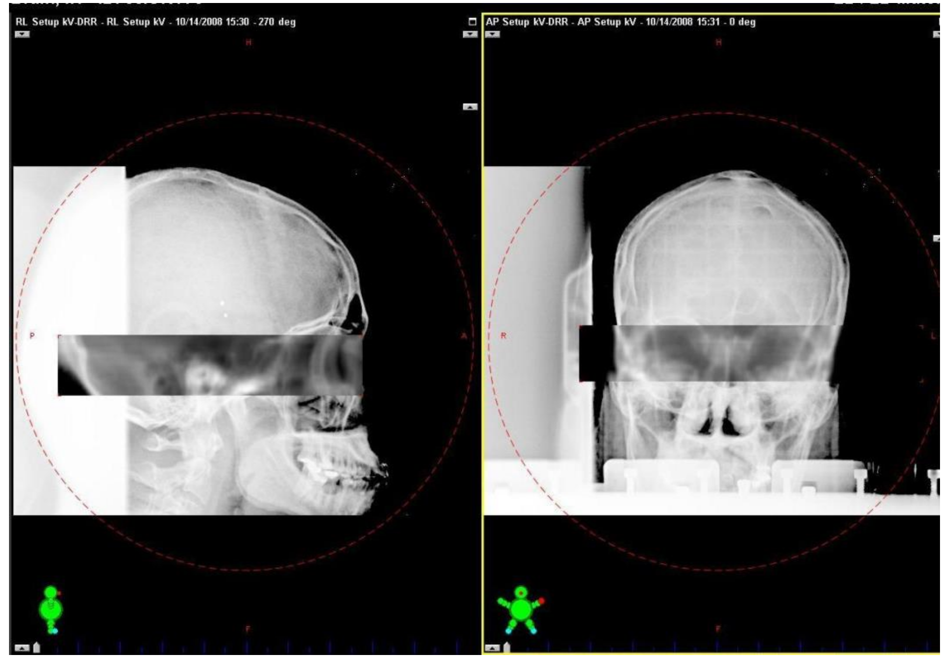
2)moving window

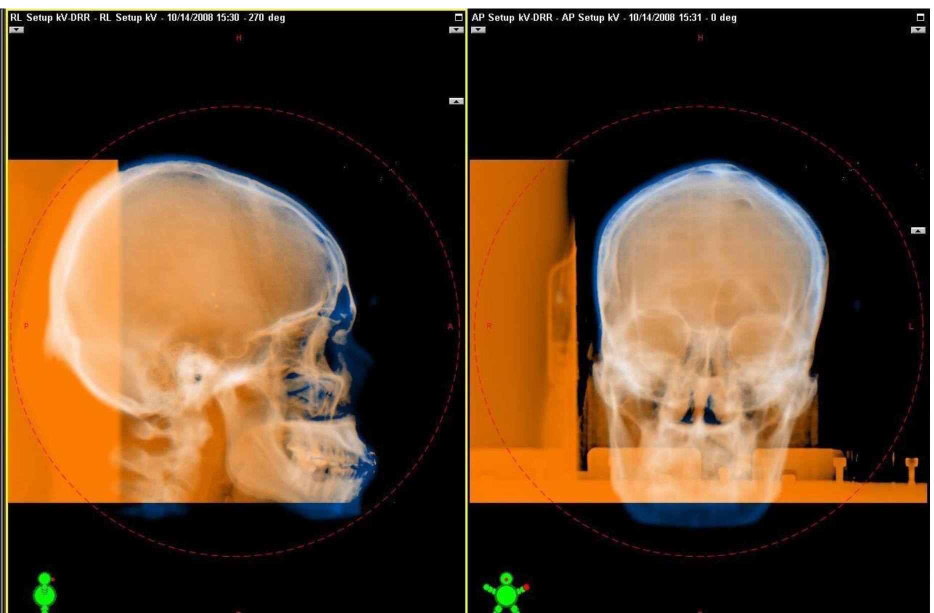
3)checker board

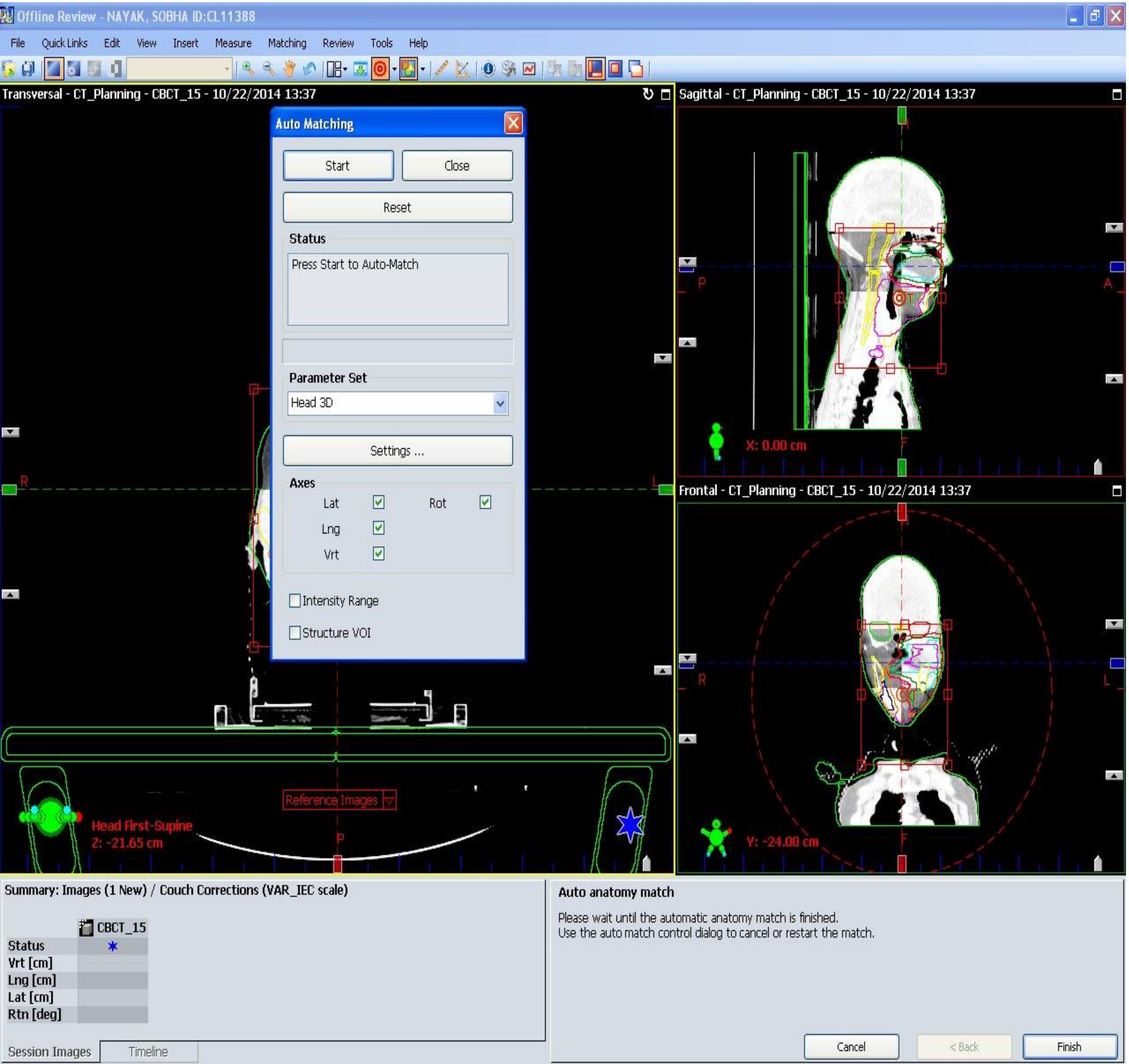
4)color blend






RL Setup kV-DRR - RL Setup kV - 10/14/2008 15:30 - 270 deg
AP Setup kV-DRR - AP Setup kV - 10/14/2008 15:31 - 0 deg


RL Setup kV-DRR - RL Setup kV - 10/14/2008 15:30 - 270 deg
AP Setup kV-DRR - AP Setup kV - 10/14/2008 15:31 - 0 deg



	CBCT_15
Status	*
Vrt [cm]	0.0
Lng [cm]	0.0
Lat [cm]	0.1
Rtn [deg]	0.0

Summary

- One must follow SOP's in entire workflow
- Evaluate, record and monitor the every process and devices periodically to minimize the errors
- Conduct periodic internal and external audits in the process
- Follow the radiation protection norms for both staff and patients/public.

BRAVERY
CARE
Paramedics Military
Emergency Services
HEROES
GRIT
Doctors
Emergency Services
COMMITMENT
Frontline Healthcare Military
Nurses
BRAVERY
SPIRIT
COURAGE
Police
Police Paramedics PASSION
Military
Healthcare
Police
Workers
DEDICATION
COURAGE
COMMITMENT
Fire Fighters
Police
Nurses
Police
Military Frontline
Frontline
Emergency Services
Healthcare
Thank
DEDICATION
BRAVERY
You
Paramedics
GRIT
COMMITMENT
Healthcare
Emergency Services
COURAGE
BRAVERY
GRIT Doctors Frontline Nurses
Paramedics
PASSION
Police
Military
Healthcare Doctors BRAVERY Military DEDICATION
Paramedics
SPIRIT
Nurses
SPIRIT
DEDICATION
PASSION
GRIT
Paramedics
Fire
Fighters
SPIRIT
Nurses
GRIT