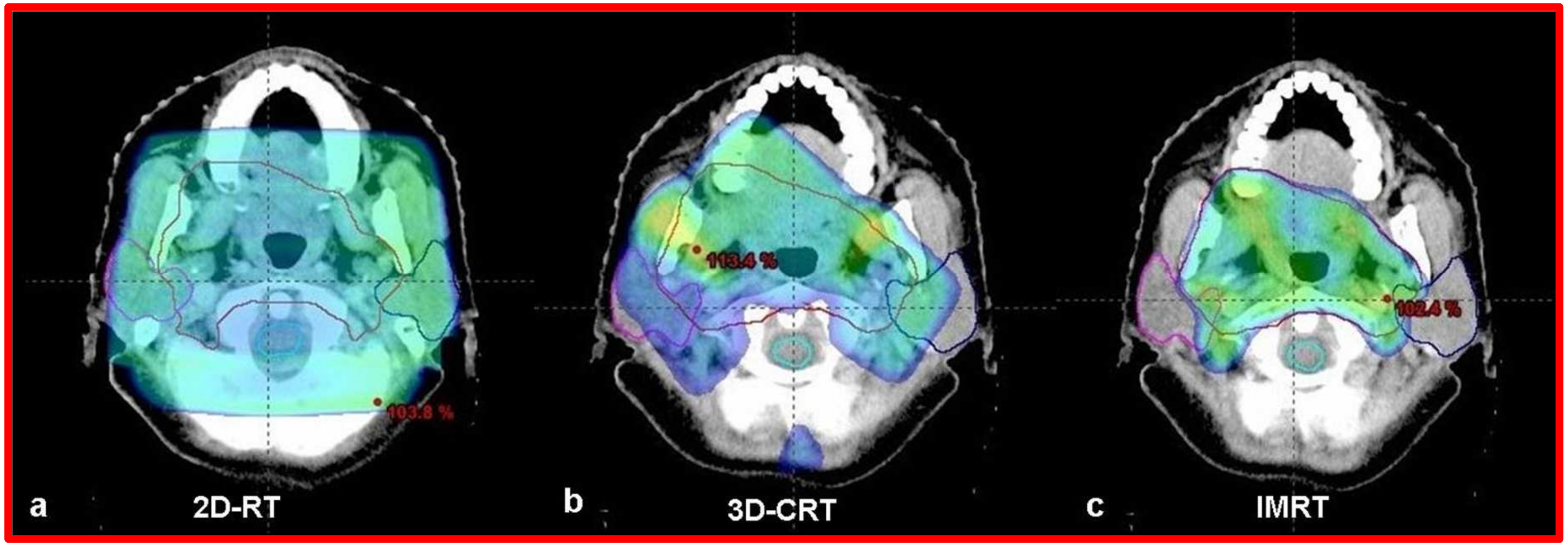

Head-Neck Cancer Radiotherapy:
Transition from 2D-RT to 3D-CRT

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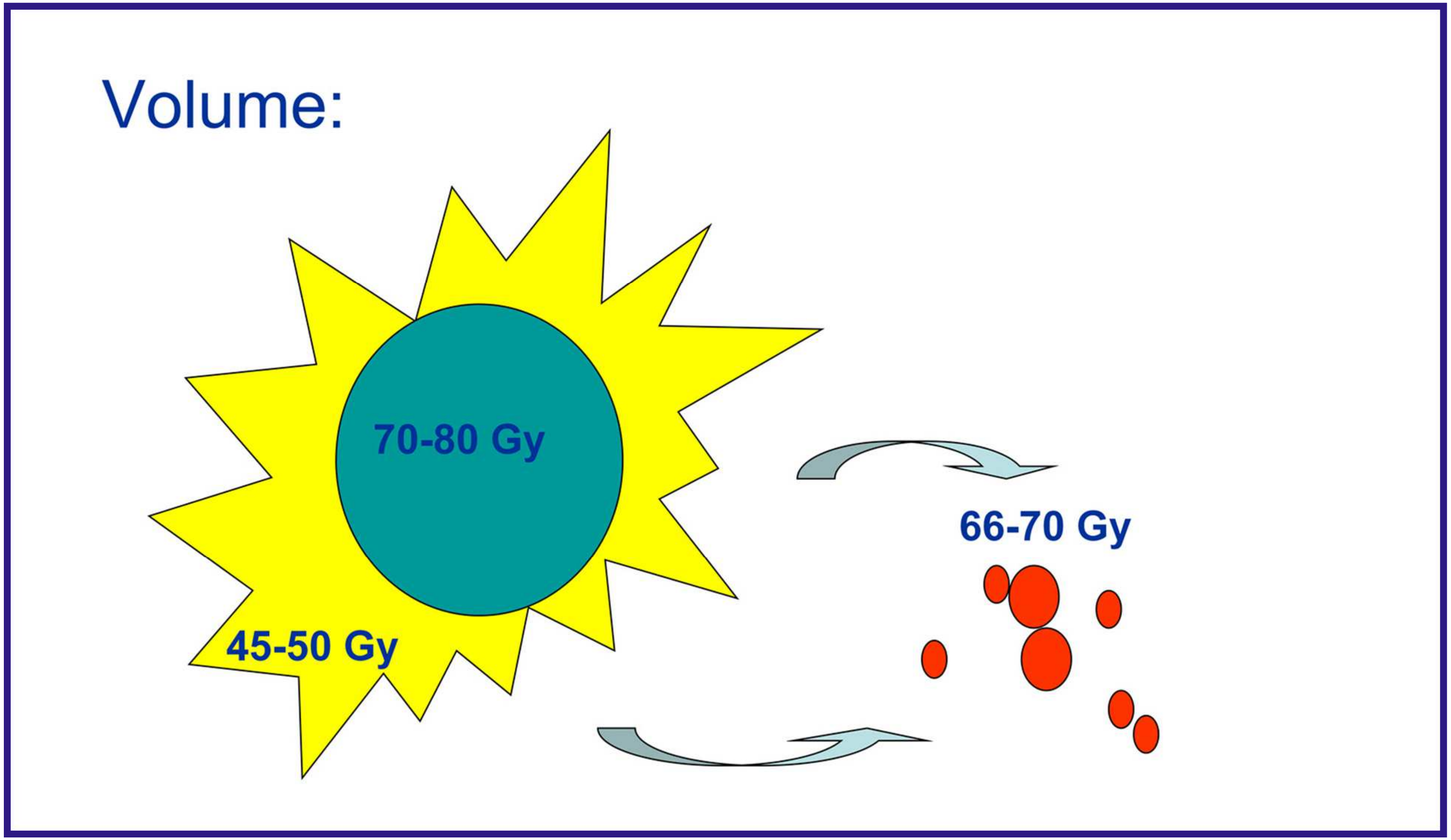
Associate Professor, Radiation Oncology
ACTREC, Tata Memorial Centre, Mumbai
ICRO Teaching Course, IGMC-RCC, SHIMLA

Head-Neck Cancers

- Aim of treatment:
  - Highest possible loco-regional control
  - Preservation of function
  - Good cosmetic result
  - Best quality of life outcome

Radiotherapy remains an integral component of the management of head & neck squamous cell carcinoma both in the definitive & post-operative adjuvant setting

Typical radiotherapy doses for HNSCC



Fletcher et al, IJROBP 1983

Challenges in optimal delivery of conventional radiotherapy for head-neck cancers

- Close proximity of tumour and critical structures/organs
- Tolerance of normal tissue limits delivery of optimum high dose
- Contour variations and tissue heterogeneity present a challenge to dosimetric planning
- Set-up uncertainties exist (5mm-1cm)

Harsh Reality

Toxicity of Head-Neck RT

Sticking

No appetite

Pain

Trismus

Nausea

Vomitting

Dry thr

Mucositis

No taste

Dry mout

Choking

Swelling

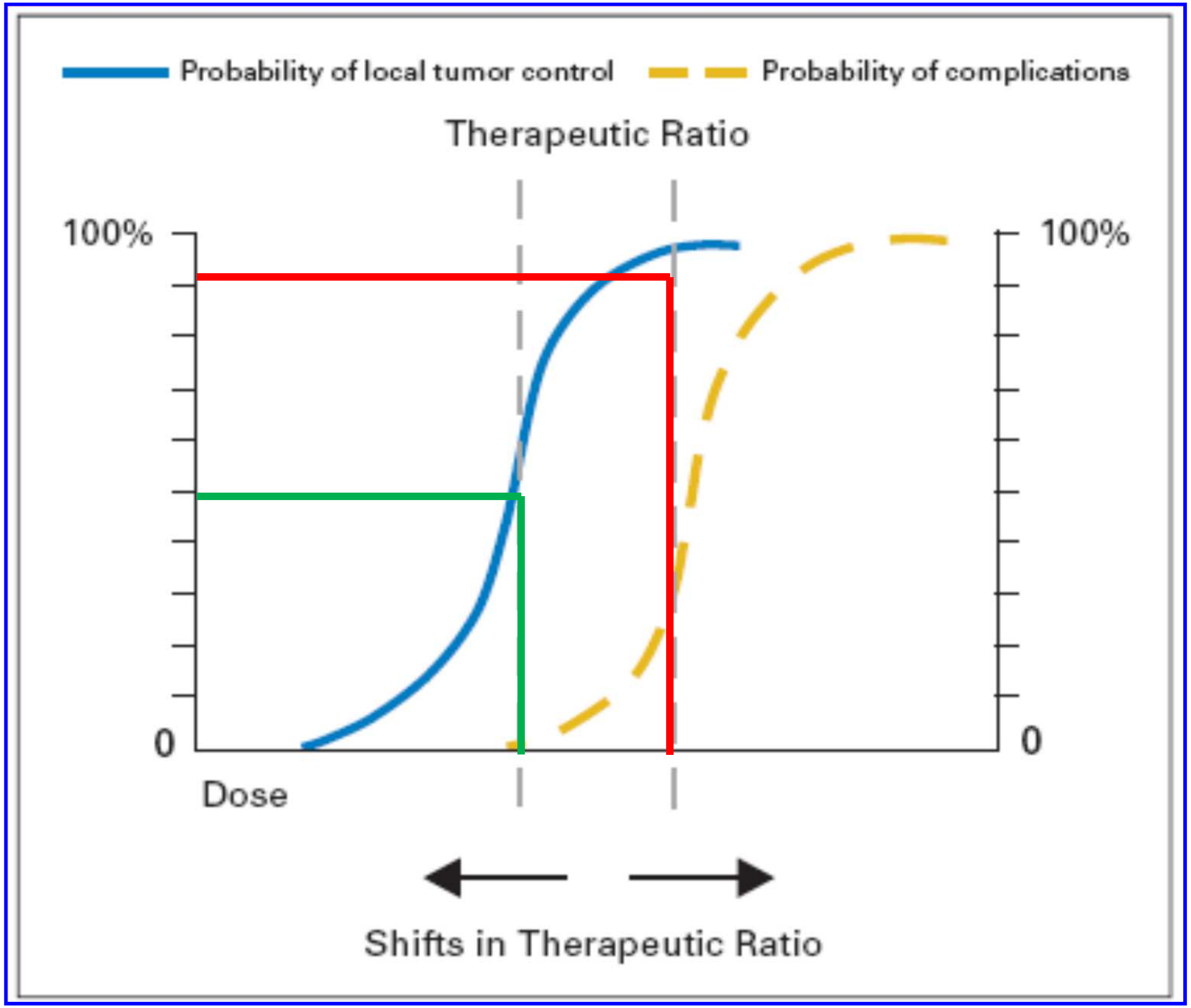
Fistula

No energy

Stitches

Fatigue

Dose response curve in head-neck cancer



Aim

- To introduce the concept of 3D CRT and describe the requirements for transition from 2D RT to 3D CRT and IMRT

Specific objectives

To identify

- **Differences between 2D-RT and 3D-CRT**
- **Chain of processes in 3D-CRT**
- **Transiting from 2D-RT to 3D-CRT**

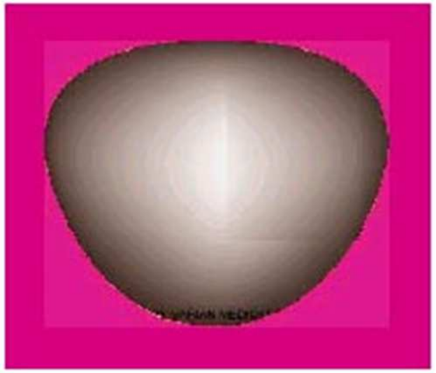
Some formal definitions

2D-RT: Use of one or more fields in a relatively simple beam arrangement with no emphasis on beam shaping for normal tissue shielding. Planning on a TPS not entirely necessary as dose distribution is generally intuitive

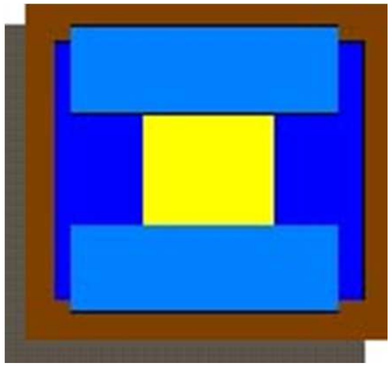
2.5D: Field shaping of conventional radiotherapy portals using blocks or MLCs (either on simulator films or CT-dataset). Dose wash can be generated if CT-dataset is used

3D-CRT: Use of multiple fields from different directions based on BEVs seen on the TPS capable of 3D-dose calculation with display of dose-distribution

Conventional 2D-RT - 1960s



Pink = treatment field or area hit by beam



Primary collimator shapes beam

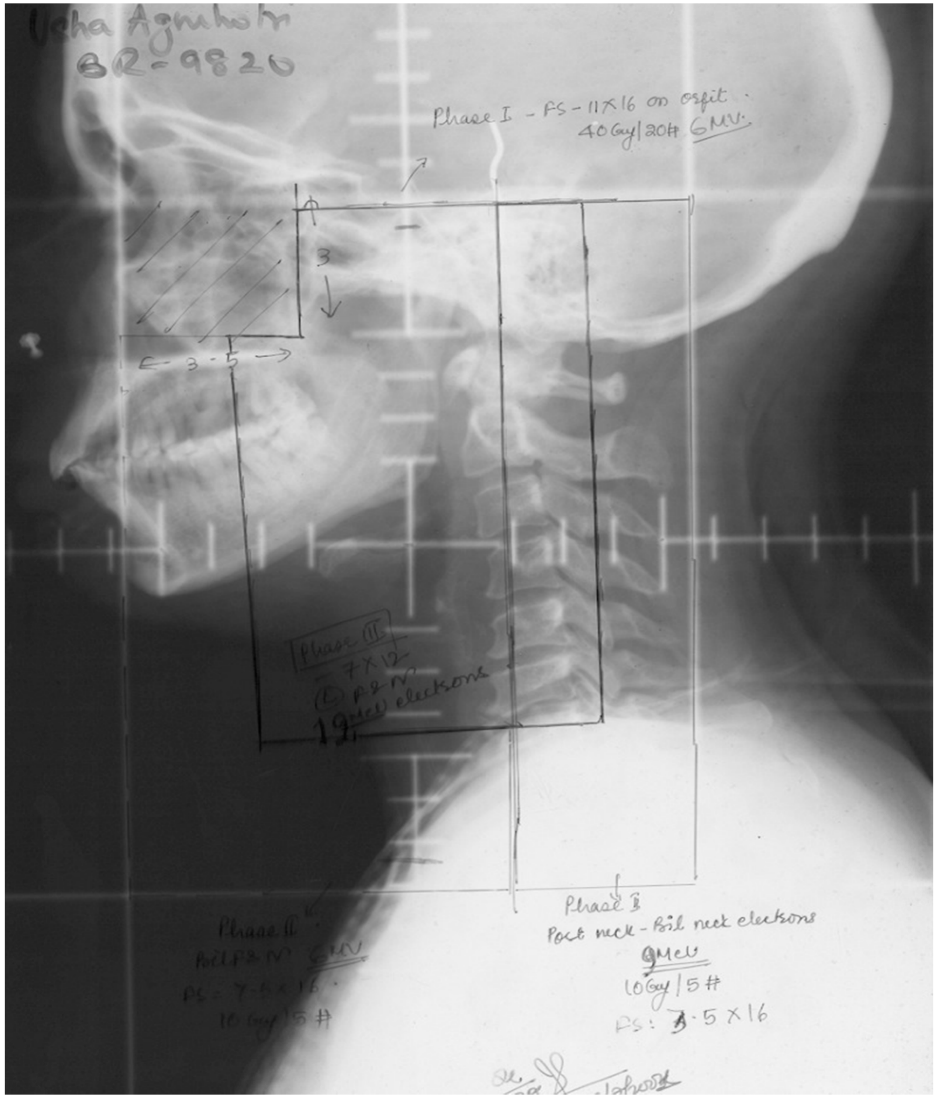
- **Simple treatment delivers uniform doses from 2-4 beam angles**
- **Beam shape is either rectangular or square**
- **Beam hits healthy tissue as well as tumor tissues**
- **Doses have to be kept low to minimize harm to normal tissue**

2D-RT

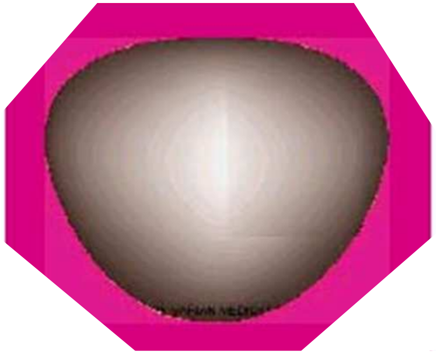
- Tumor volume and critical structures are drawn on orthogonal sim films or on few CT images
- Simple setups with 3-4 fields
- Treatment planning with isodose plans on 1-3 planes
- Broad margins are used

Two-dimensional (2D) RT for Head-Neck Cancers

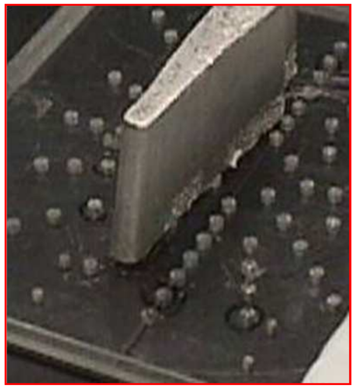
- Bilateral field or antero-lateral wedge pair portals
- Matching third low anterior neck field added sometimes
- Acceptable local control
- Higher doses to normal critical structures
- Resultant higher toxicity
- Potentially poorer QOL



Early Beam Modifiers - 1970s & early 80s



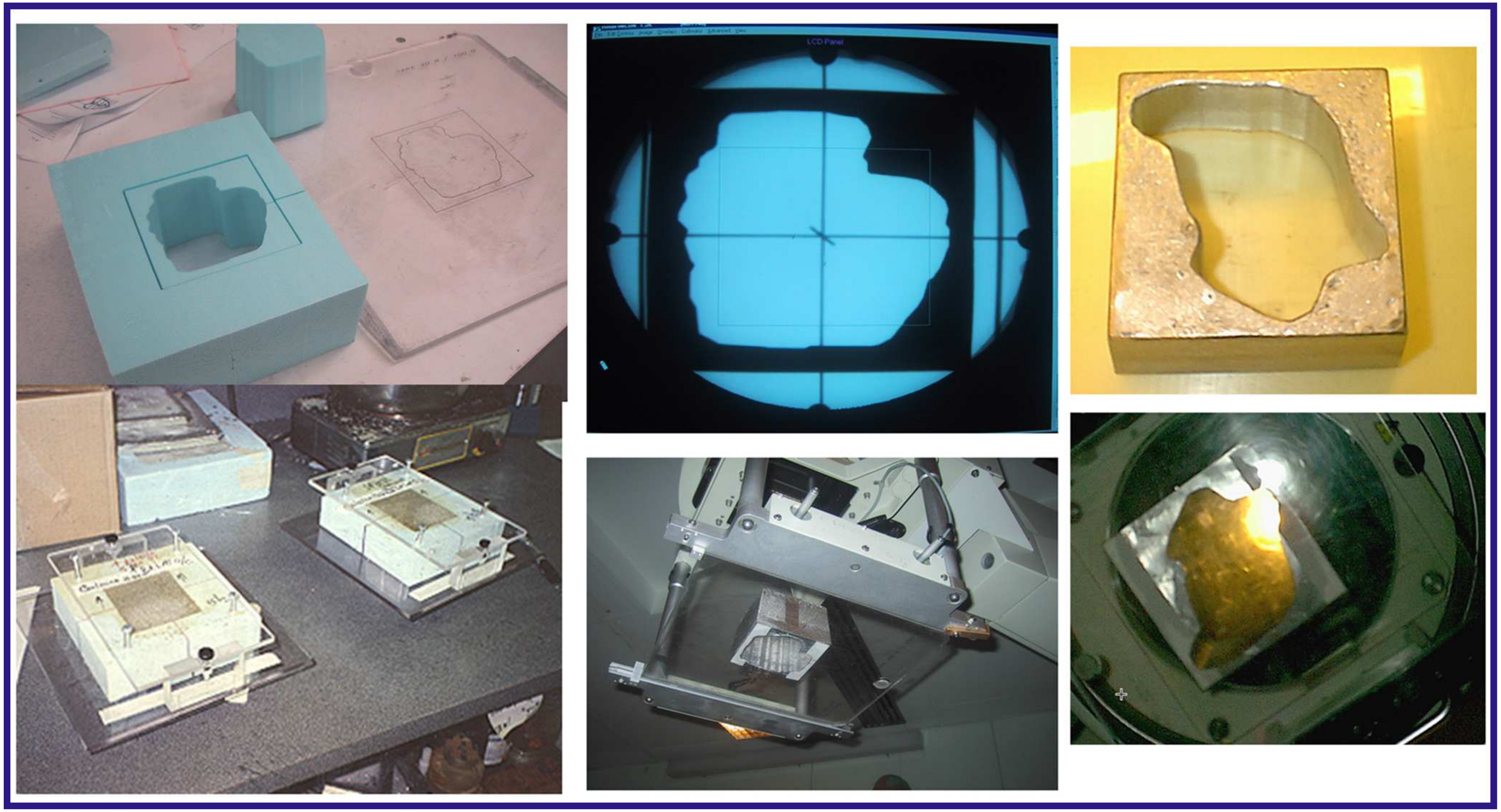
Roughly shaped treatment field



Wedge helps to modify dose distribution

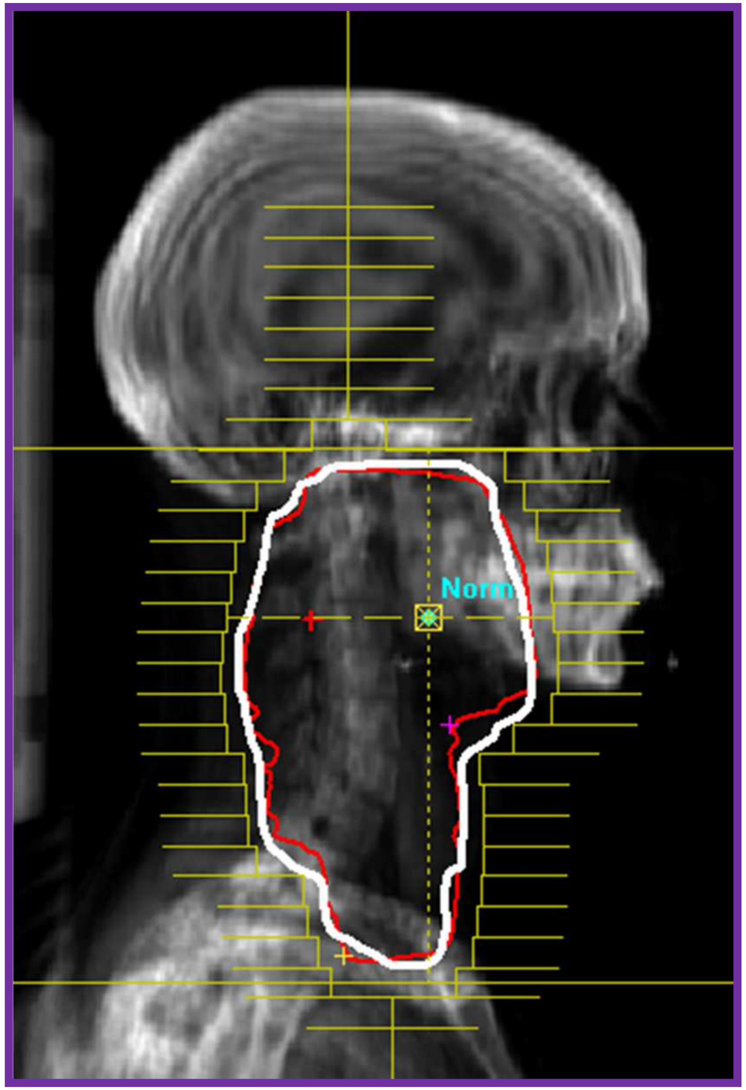
- Blocks & wedges used to shape beams and begin sparing healthy tissue
- Blocks are changed by hand for each beam angle
- Labor intensive process requires therapist to enter room repeatedly
- Typical treatments use 4 beam angles
- Dose still kept relatively low

Simple field shaping of conventional bilateral portals using cerrobend blocks



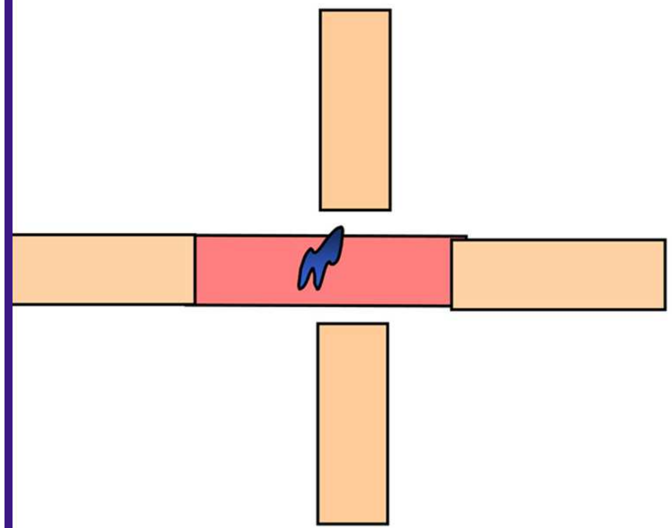
2D-RT (conventional open fields)

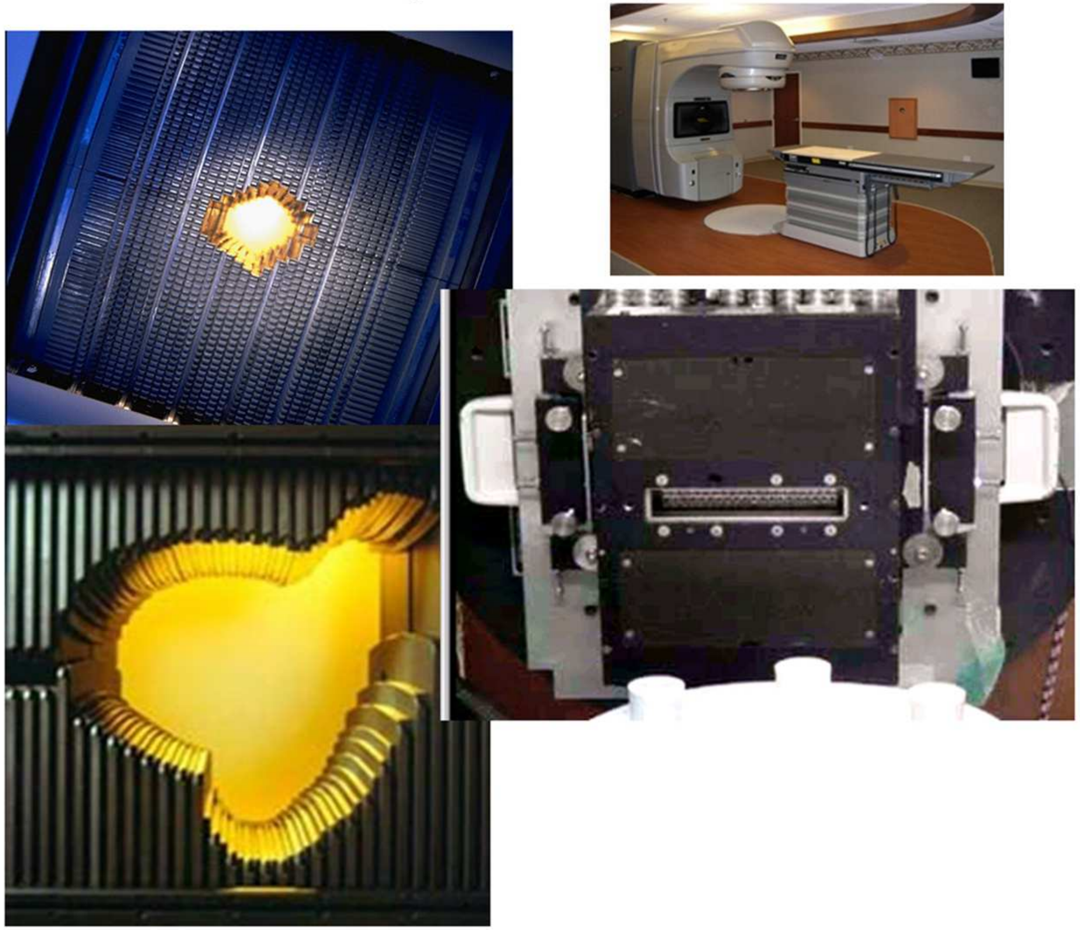
2.5D-RT (conventional shaped fields)



Bilateral fields: The 95% isodose line (white) is superimposed on PTV (red)

Multi-leaf Collimator (MLC):
True enabler of conformal radiotherapy

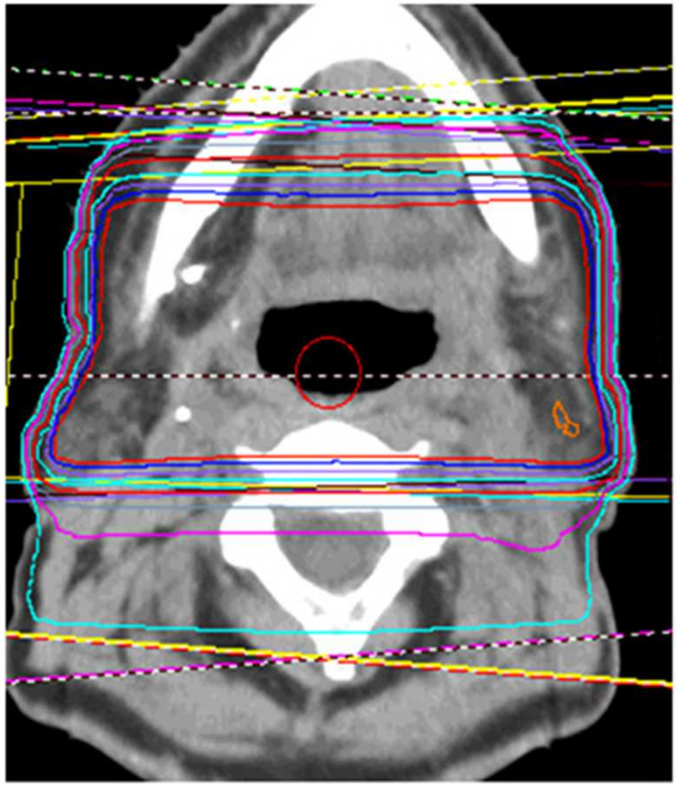




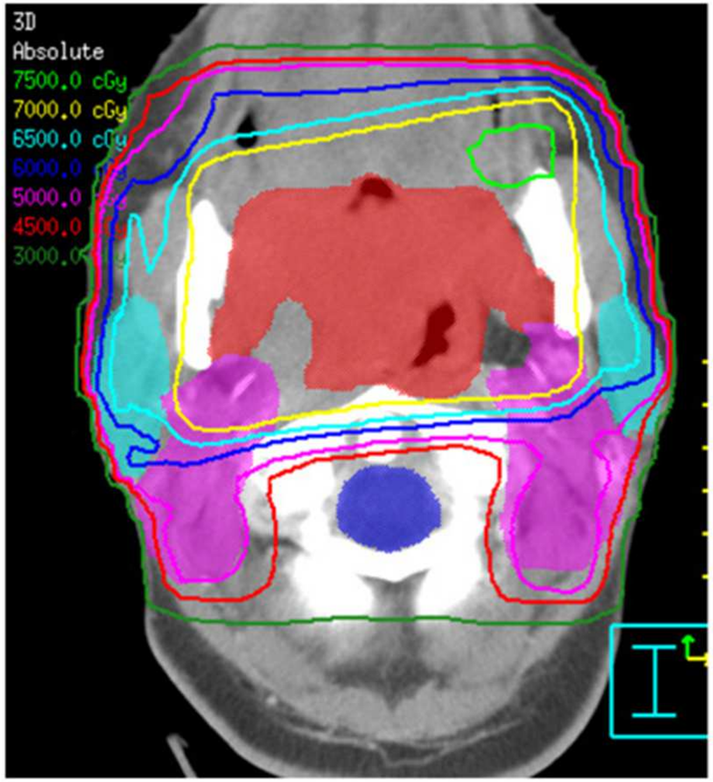
3D-CRT

- Tumor volume and critical structures are drawn on slice-by-slice CT or MR images. Beams-eye-views s are created from digitally reconstructed radiographs
- Complex setups of 4-6 fields with precise immobilization
- 3D treatment planning with 3D visualization and plan analysis
- Tight margins are used

From parallel opposed (2D) to multi-field 3-dimensional conformal radiotherapy (3D-CRT)

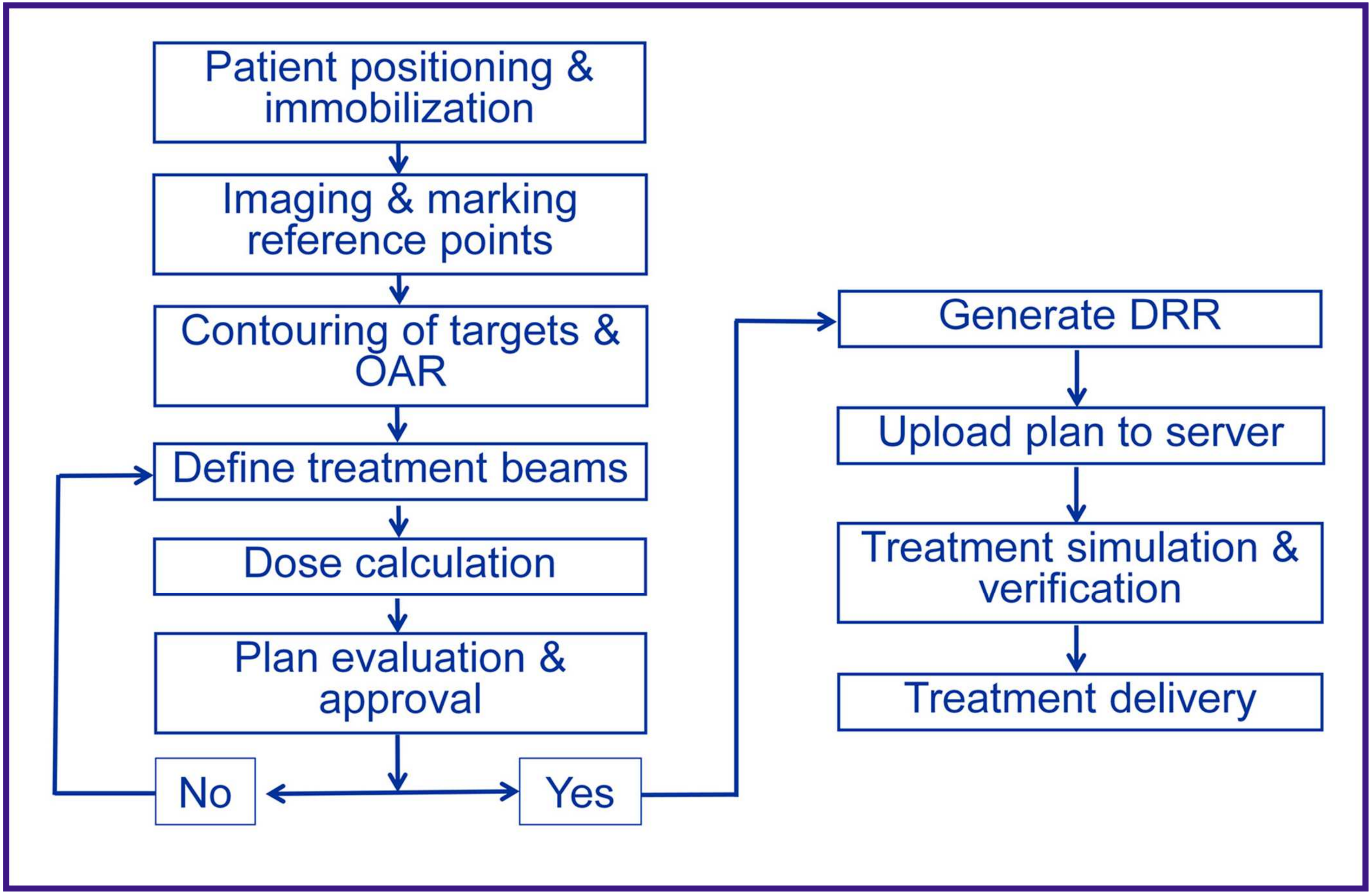


2D RT

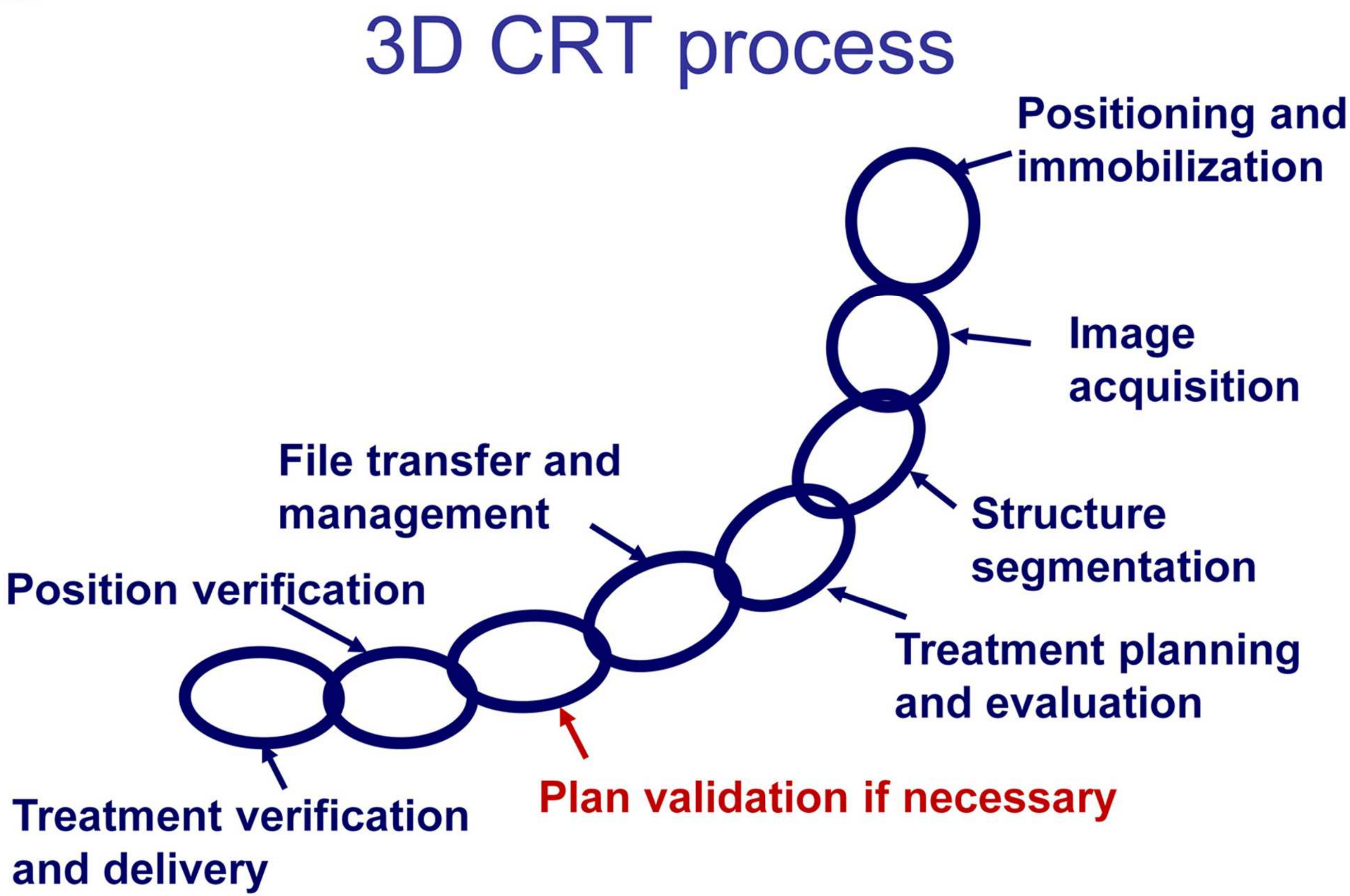


3D CRT

Typical 3D-CRT workflow



Chain of Processes in Conformal Radiotherapy

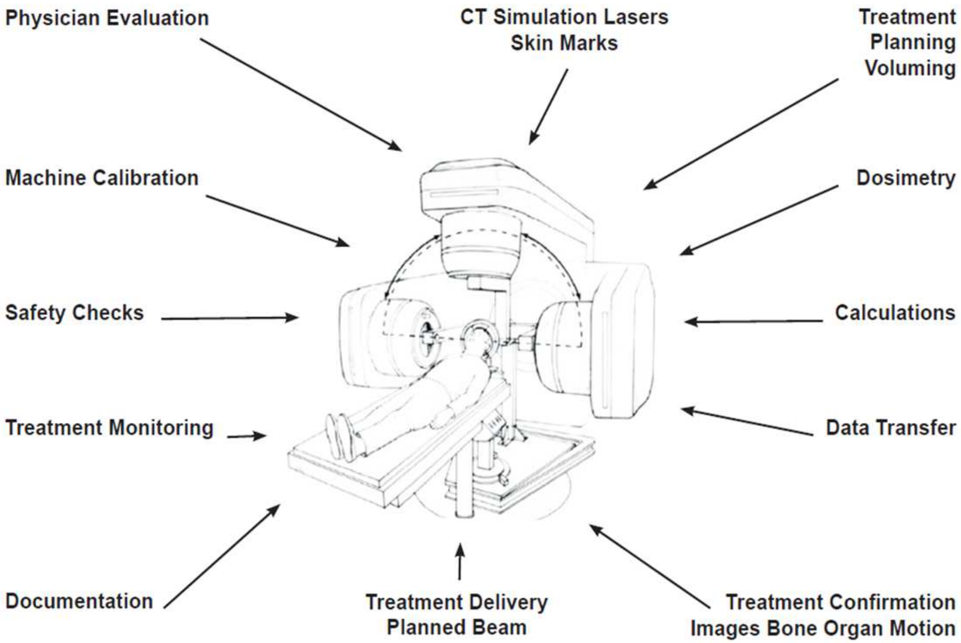


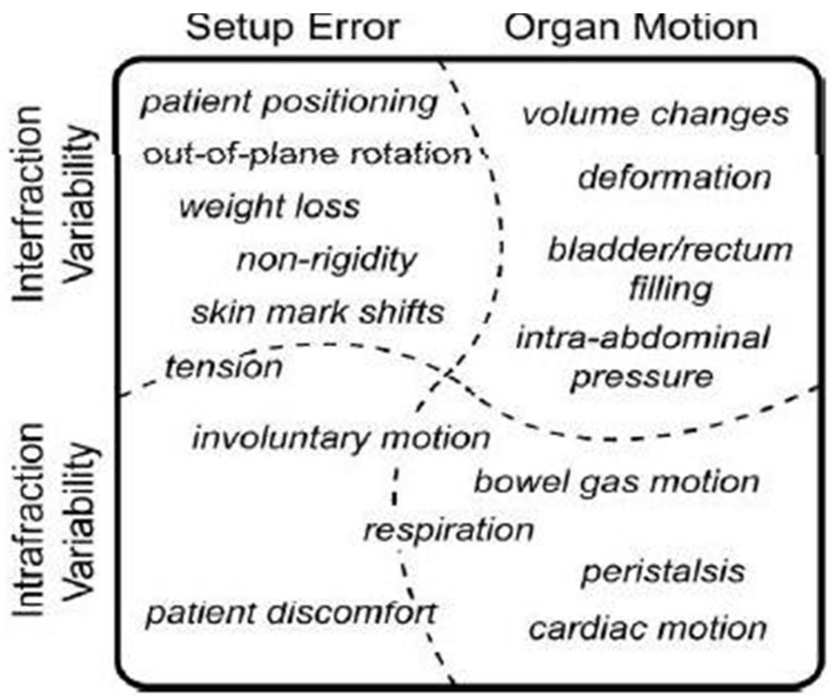
Rationale of conformal radiotherapy in head-neck cancers

- **Achievement of dose escalation:**
  - To improve loco-regional control
  - To increase overall survival
- **Reduction of normal tissue complications:**
  - To improve quality of life

All this requires a high level of accuracy

Major sources of uncertainty & errors in the radiotherapy process





Accurate treatment requires thorough understanding of uncertainties

Set-up errors - 1

- Set-up errors:

  Discrepancy between intended and actual treatment position.

  - **Random Errors:** Inconsistent deviation
  - **Systematic Positioning Errors:** Recurring error

- **Random Errors:** Inconsistent deviation
  - Patient movement and organ motion
  - Inconsistent repositioning
  - Variables in equipment and devices
  - Inconsistent interpretation of skin marks

Set-up errors - 2

- **Systematic Positioning Errors:** Recurring error
  - Target delineation error
  - Change in target position and/or shape
  - Transfer error
  - Misinterpret set-up instructions
  - Blocks incorrectly cut/prepared
  - Discrepancies between simulator, treatment unit etc.
  - Treatment plan transcription errors

Principles of accurate set-up

- Place patient in comfortable, relaxed position
- Always check that the patient is straight
- Use modern laser system
- Extend the surface markings superiorly and inferiorly
- Reference the patient position (e.g. tilt of head) and field to external anatomical landmarks (and to bony landmarks wherever possible) and record carefully
- Make use of immobilisation devices

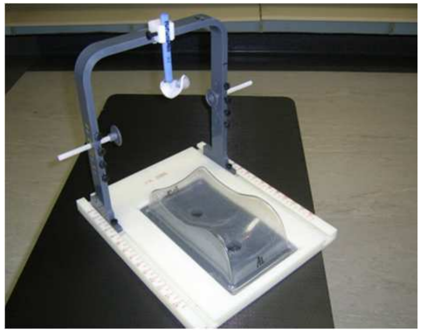
Principles of immobilization

- **Immobilisation essential for all radiation therapy:**
  - Comfort
  - Stability
  - Precision
  - Efficiency

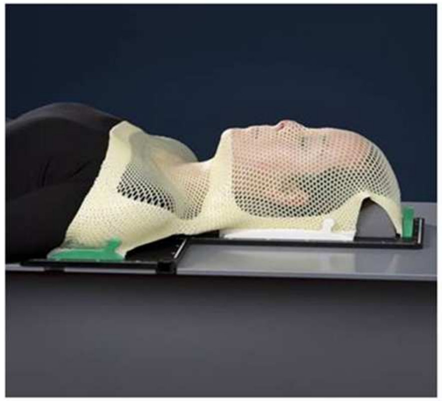
- **Immobilisation devices (positioning systems) are used to**:
  - maintain the patient in a comfortable and stable position
  - aid consistently reproducible treatment position
  - contribute to achieving accurate treatment
  - enhance the efficiency of the treatment set-up
  - reduce random set-up errors

Immobilization devices in head-neck RT

- Sellotape (unsatisfactory)
- Head rest alone (unsatisfactory)
- POP with head rest
- Mouth bite (nasion and chin support)
- Perspex cast
- And…



Most commonly used

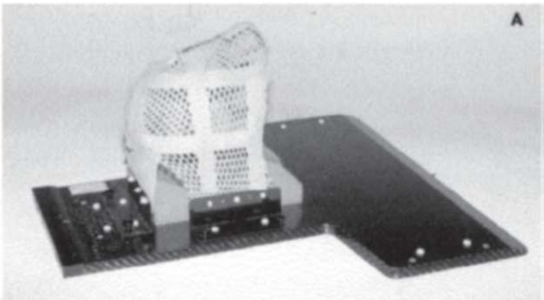


- Thermoplastic masks
  - 3 Clamp
  - 4 Clamp
  - 5 Clamp

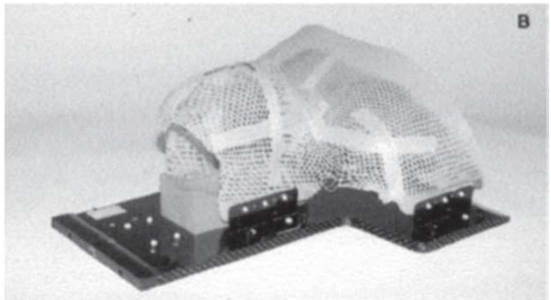
The fixation force, precision and stability of immobilisation by means of low melting temperature thermoplastic devices depends on:

- Type of thermoplastic material
- Design of head board/rest

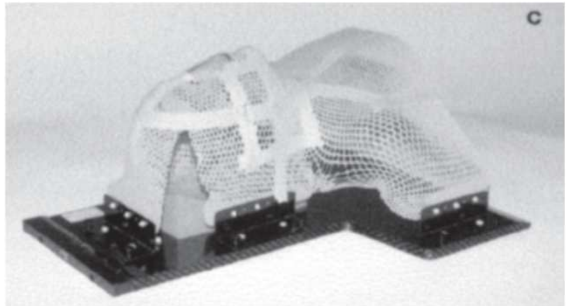
Set-up accuracy of commercially available thermoplastic masks



Three clamp



Four clamp



Five clamp

4-Clamp mask was better than 3-clamp or 5-clamp mask for random errors

Set-up margins of 5mm are adequate in HN RT

Radiother Oncol 2001

Radiat Oncol 2007

Guidelines for positioning in head-neck RT

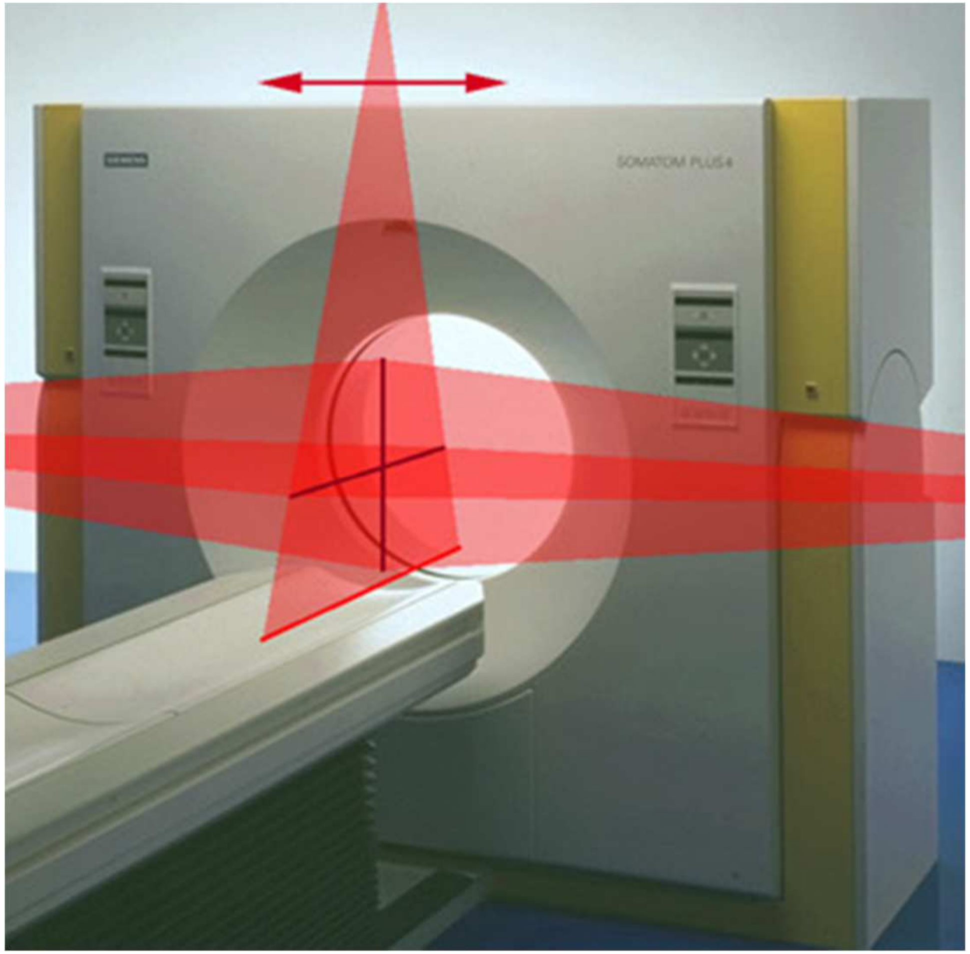
- Localize patient with neutral, hypo- or hyper-extension of the neck position as relevant
  - Minimize intra-fraction patient motion
- Use customized head rest and mask
  - Improve accuracy
- Index immobilisation devices to treatment couch
  - Improves set-up efficiency and accuracy
- Use active patient position monitoring system (LED camera System)
  - Improves set-up accuracy and reproducibility
  - Minimize intra-fraction patient motion

CT-simulation:
imaging for conformal planning

- High resolution, diagnostic images
- 3-D reconstruction capabilities
- 3-D tumour localization
- 3-D organs at risk localization
- CT number/electron density data
- Networked to treatment planning

CT-Simulation -1

- Mechanical
  - Large aperture
    - (70 or 85 cm)
  - Flat couch top insert
  - Positioning lasers
  - Accurate couch positioning (< 1 mm)



CT-Simulation - 2

- Imaging system
  - State-of-the-art diagnostic imager
  - Large circle of reconstruction (> 50 cm)
  - Rapid scan capabilities (3-D) (spiral scan)
  - 3-D reconstructions (sagittal, coronal, etc.)
    - Transferrable to TPS
  - Transmission scans (AP, lateral, other)

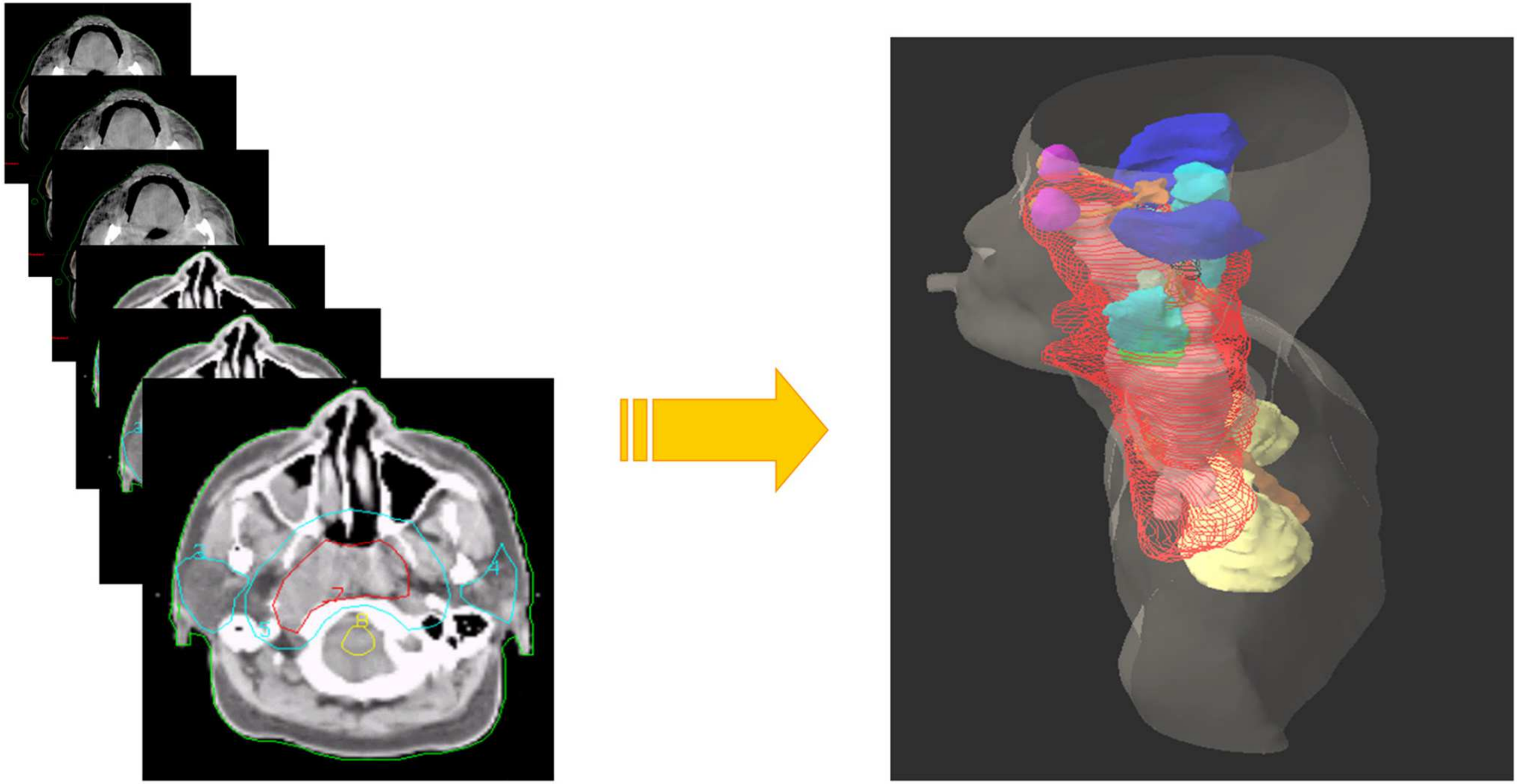
CT-Simulation - 3

- Considerations for RTP
  - Scan patient in RT position
    - Flat couch top, lasers
  - Respiratory conditions
  - Reference marks – radio-opaque
  - Immobilization devices
  - Changeable organs
- Auto injector for IV contrast injection
- Network interface
  - Digital Imaging and Communications in Medicine (DICOM)

CT-Simulation: imaging parameters

- Slice thickness
  - Spiral/Helical – thin cut for clearer DRR
  - MultiSlice – ↑ resolution, ↓ acquisition time, ↑ volume
- Pre-Set Scanning protocol
  - mAs, kV, index, pitch, FOV, pilot length, pilot orientation, etc
- No gantry tilt
- Contrast media and image quality

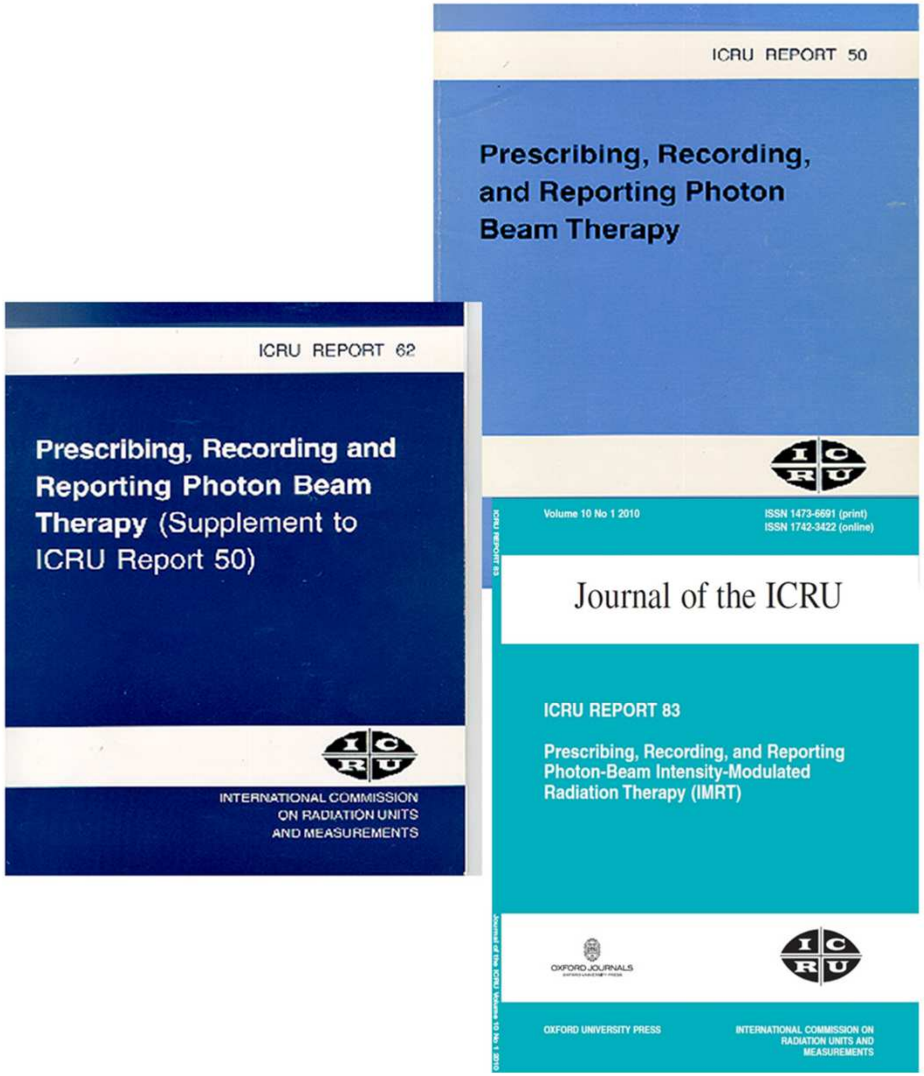
Structure segmentation for conformal planning



Guidance on prescribing & reporting

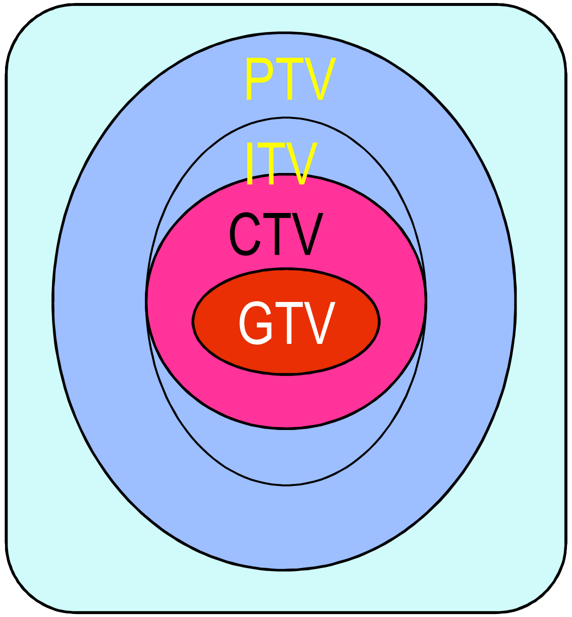
The ICRU 50, 62 and 83 Reports define and describe several target and critical structure volumes that:

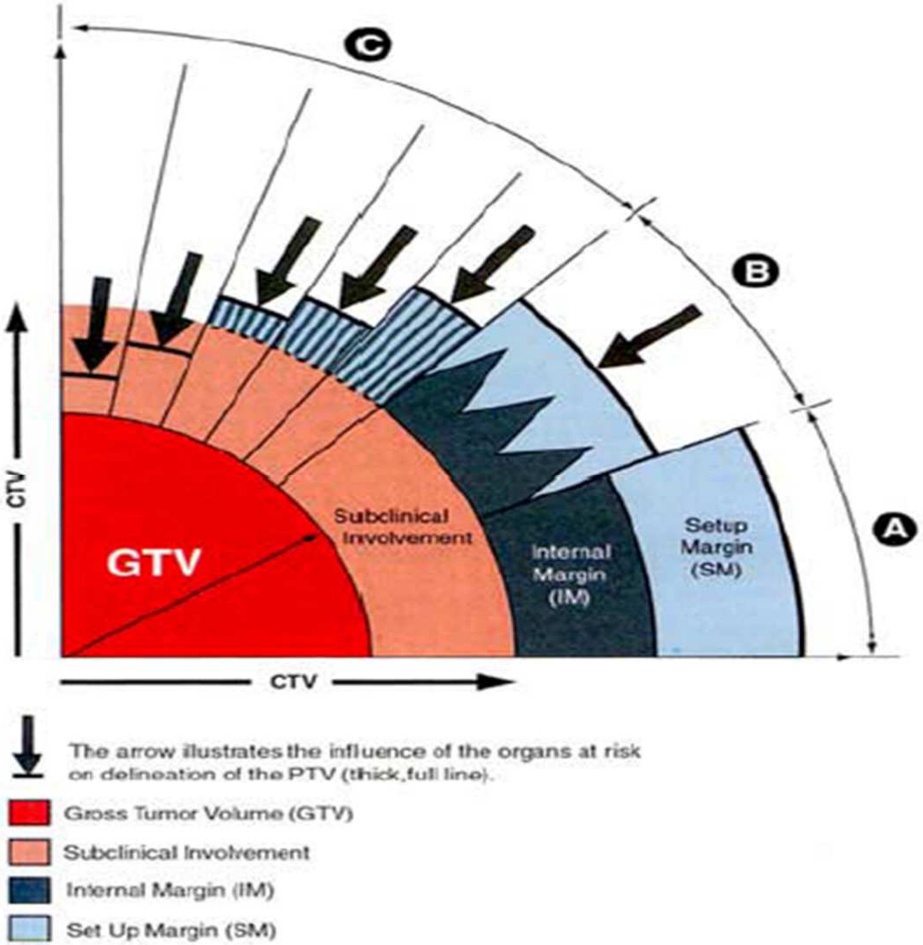
- aid in the treatment planning process
- provide a basis for comparison of treatment outcomes.



Target volume delineation

ICRU 50/62/83 guidelines





GTV = Visible/palpable tumor

CTV = microscopic extension

ITV = CTV + Internal margin (IM)

PTV = ITV + Set up margin (SM)

Target volume delineation

- Good quality imaging essential for accurate delineation
- Always use adequate contrast for planning imaging
- Preferable to use multi-modality imaging & fusion
- Very crucial and critical step in conformal planning
- Highly subjective process
    - Inter- & intra-observer variability
    - Inter- & intra-modality variability
- Time/labor intensive

Probably the weakest link in the chain of processes

CT-based delineation of lymph node levels and related CTVs in the node-negative neck: DAHANCA, EORTC, GORTEC, NCIC, RTOG consensus guidelines

Vincent Grégoire[a,*,1], Peter Levendag[b,1], Kian K. Ang[c], Jacques Bernier[d], Marijel Braaksma[b], Volker Budach[e], Cliff Chao[c], Emmanuel Coche[f], Jay S. Cooper[c], Guy Cosnard[f], Avraham Eisbruch[c], Samy El-Sayed[g], Bahman Emami[c], Cai Grau[h], Marc Hamoir[i], Nancy Lee[c], Philippe Maingon[j], Karin Muller[b], Hervé Reychler[k]

Radiotherapy and Oncology 69 (2003) 227–236

Proposal for the delineation of the nodal CTV in the node-positive and the post-operative neck

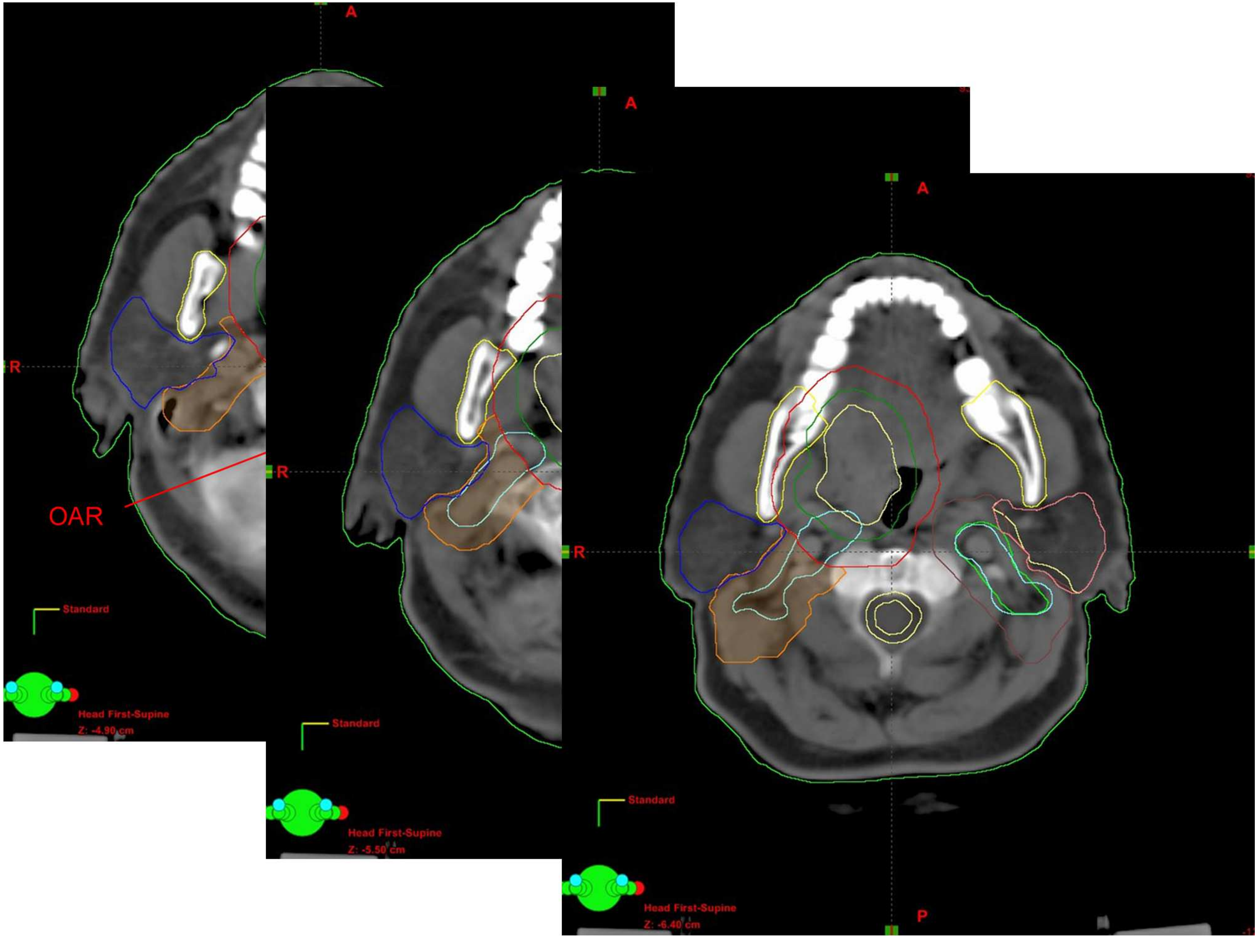
Vincent Grégoire[a,*], Avraham Eisbruch[b], Marc Hamoir[c], Peter Levendag[d]

Radiotherapy and Oncology 79 (2006) 15-20

Delineation of the neck node levels for head and neck tumors: A 2013 update. DAHANCA, EORTC, HKNPCSG, NCIC CTG, NCRI, RTOG, TROG consensus guidelines ☆

Vincent Grégoire[a,*], Kian Ang[b], Wilfried Budach[c], Cai Grau[d], Marc Hamoir[e], Johannes A. Langendijk[f], Anne Lee[g], Quynh-Thu Le[h,i], Philippe Maingon[j], Chris Nutting[k], Brian O'Sullivan[l], Sandro V. Porceddu[m], Benoit Lengele[n]

http://dx.doi.org/10.1016/j.radonc.2013.10.010



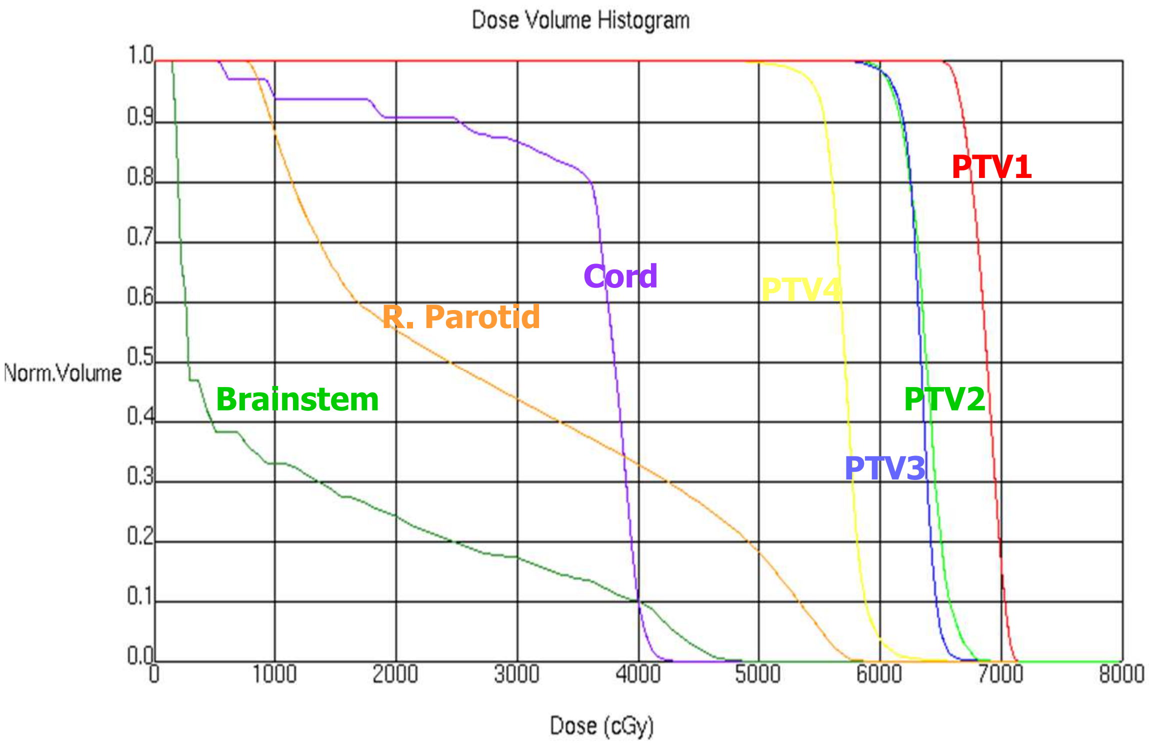
A
R
OAR
Standard
Head First-Supine
Z: -4.90 cm
A
R
Standard
Head First-Supine
Z: -5.50 cm
A
R
P
Standard
Head First-Supine
Z: -6.40 cm

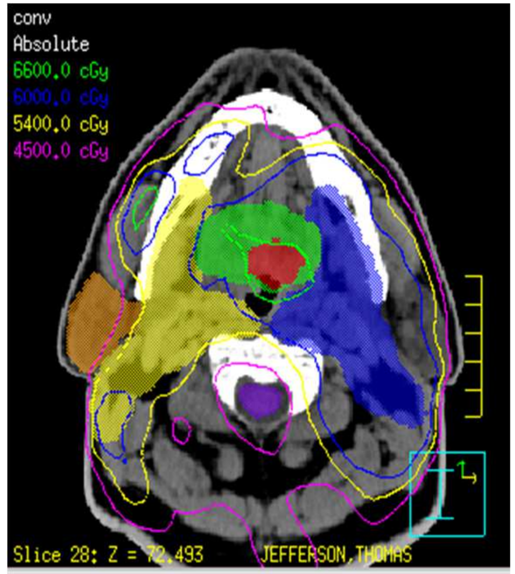
Normal Structure Delineation

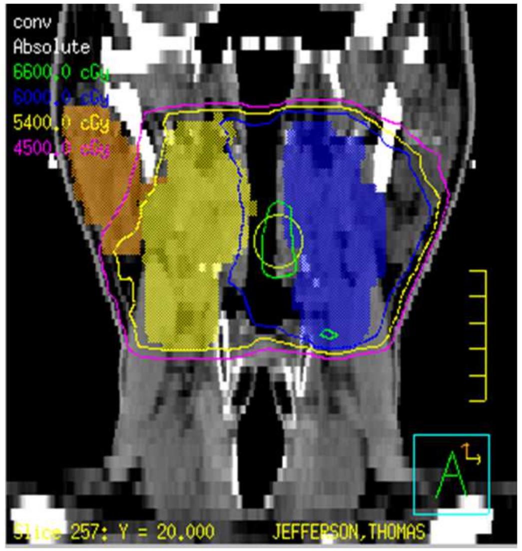
OARs

Not delineated, not avoided

Not delineated, not seen in DVH







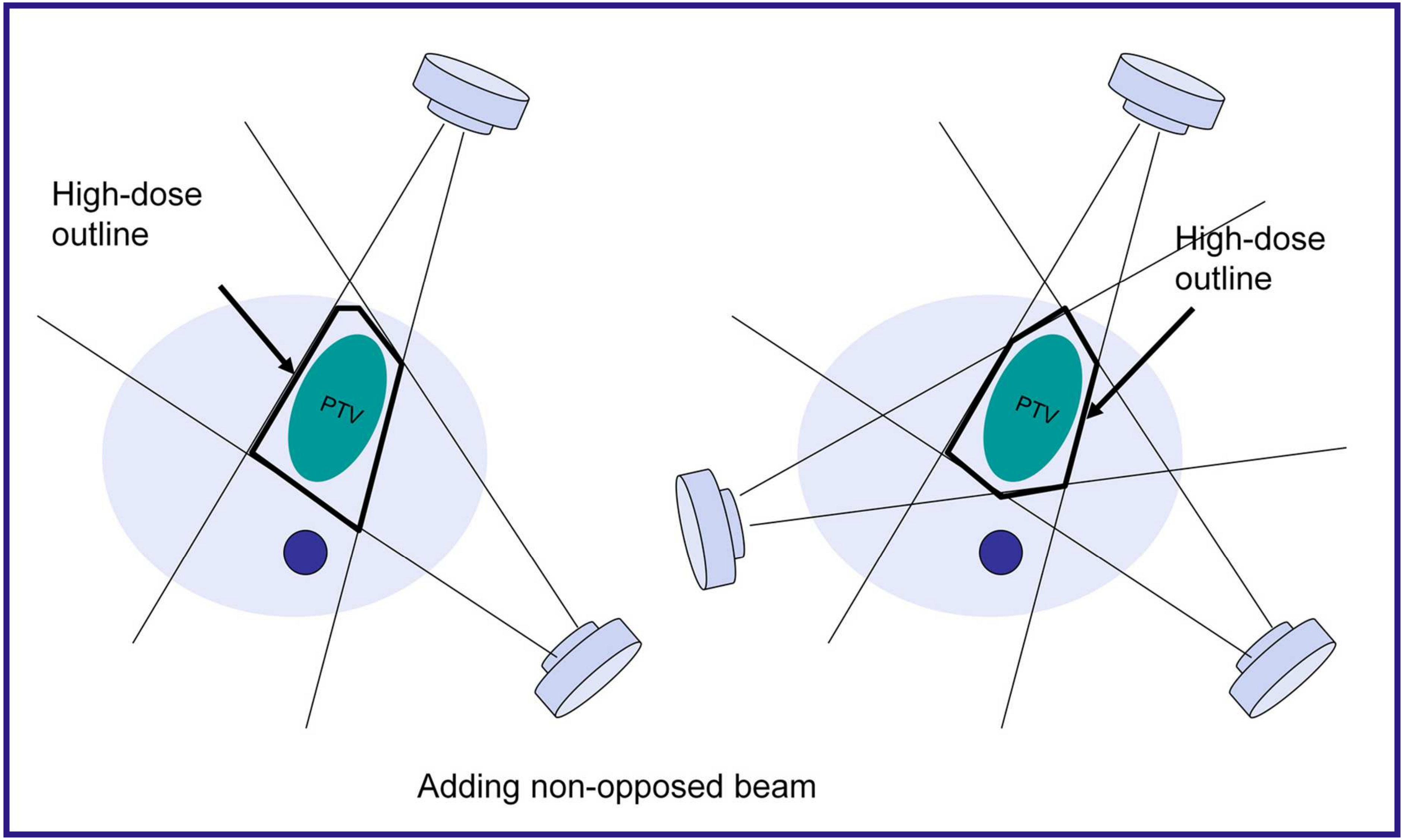
Elements in 3D-CRT planning

- Portal arrangement
- Field size
- Depth of prescription
- Use of treatment accessories
- Dose per fraction
- Treatment time/ Monitor unit calculation

General principles of field arrangement in 3D-CRT for head-neck cancers

- **Avoid direct beam entry through an OAR (not always possible)**
- **Use beam splitting (partial blockage of the beam) to shield OAR**
- **Add more beams in the arc closer to the target**
- **Avoid parallel opposed beams (reduces high-dose conformity)**
- **Use compensative fields to improve homogeneity**
- **Use wedges & weightage to improve homogeneity & conformity**
- **Use non-coplanar beams (if necessary): eg. sino-nasal targets**

Schematic representation of field placement



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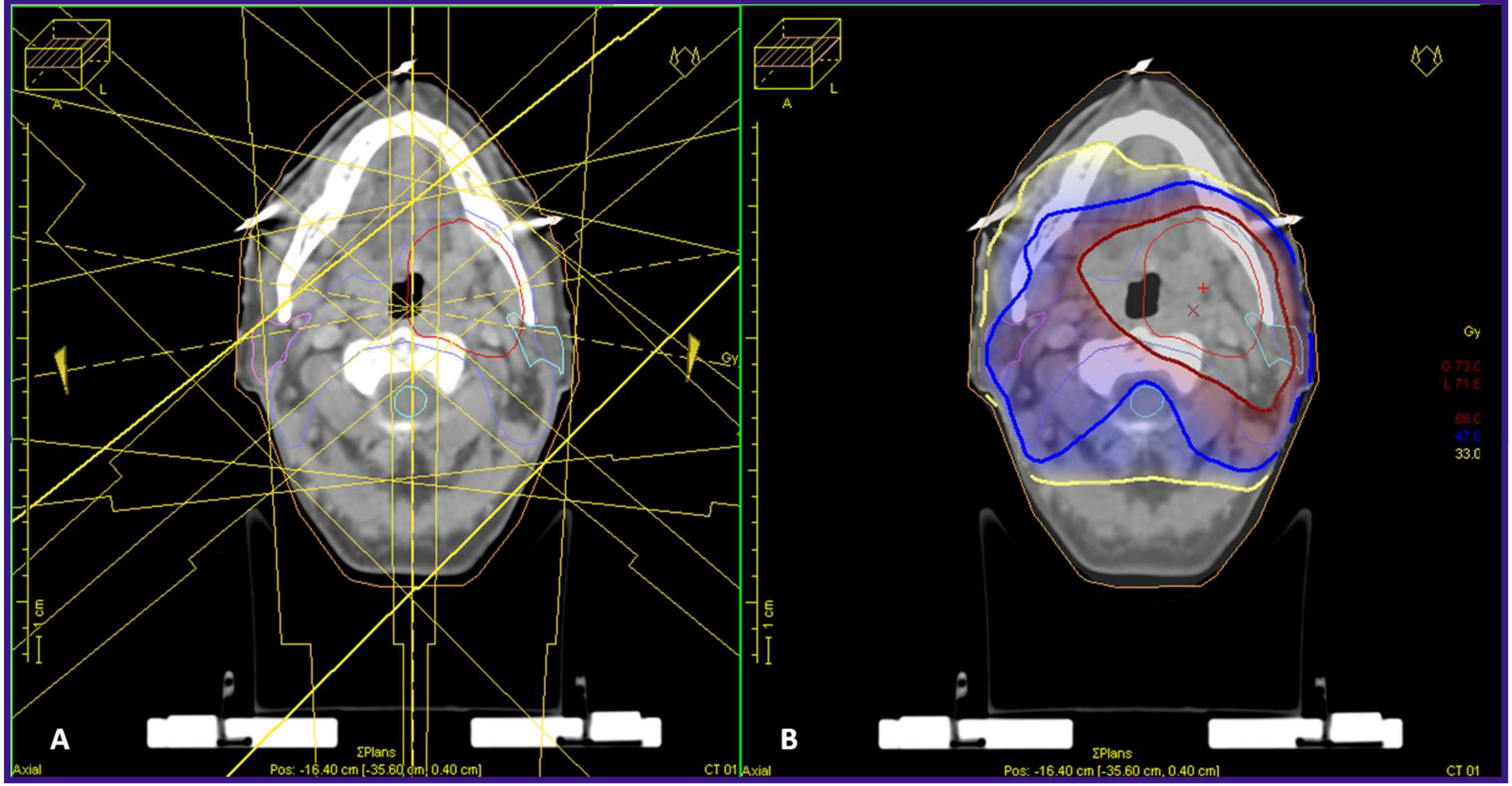


Typical beam arrangement for HN 3D-CRT

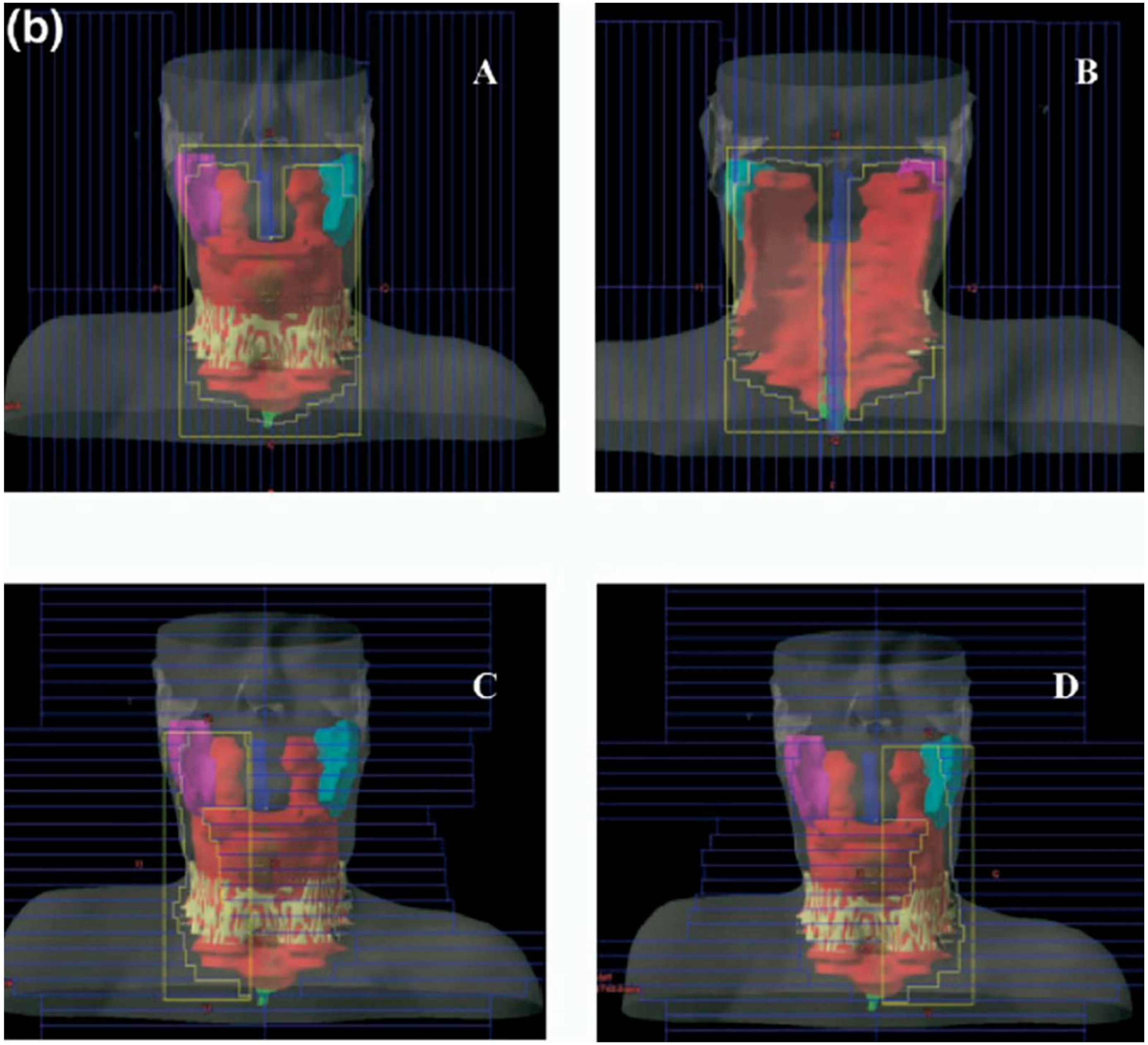
Field name	Gantry angle (°)	Weight	Wedge
Anterior	0	3.50	—
Anterior DX	0	0.5 (compensative)	—
Anterior SN	0	0.5 (compensative)	—
Oblique Anterior DX	280	0.8	—
Oblique Anterior SN	80	0.8	—
W Oblique Anterior DX	280	1.1	Enhanced dynamic
W Oblique Anterior SN	80	1.1	Enhanced dynamic
Oblique Posterior DX	220	1.4	—
Oblique Posterior SN	135	1.4	—
Posterior	180	1	—
Compensative	0 or 180	0.6 (compensative)	—
Other compensative fields*	As needed	As needed (compensative)	—

Abbreviations: DX = right; SN = left.

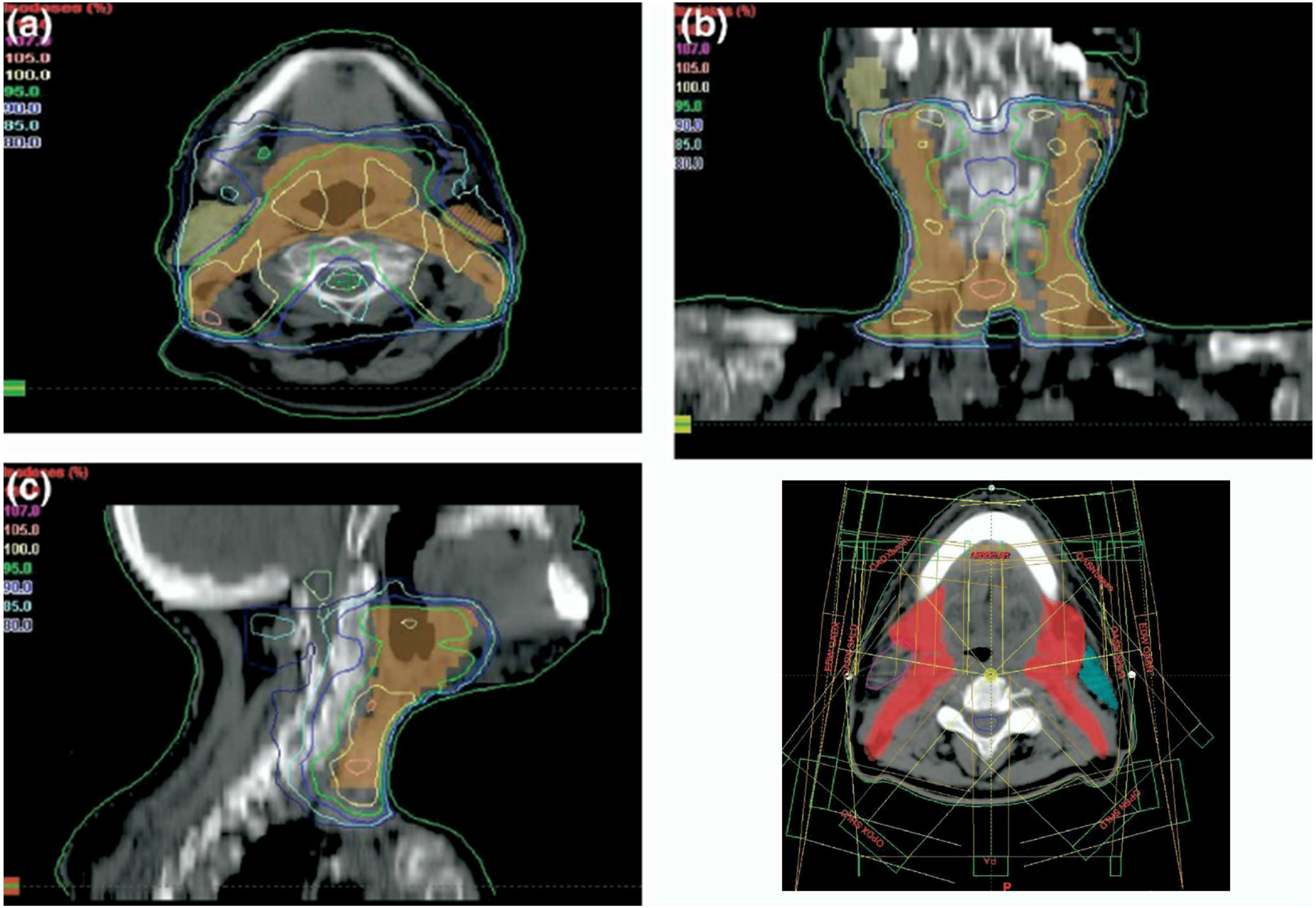
* To fill eventual holes in dose distribution due to tissue nonhomogeneity, especially along neck and at mandibular level.

Generally based on beam's eye view (BEV)

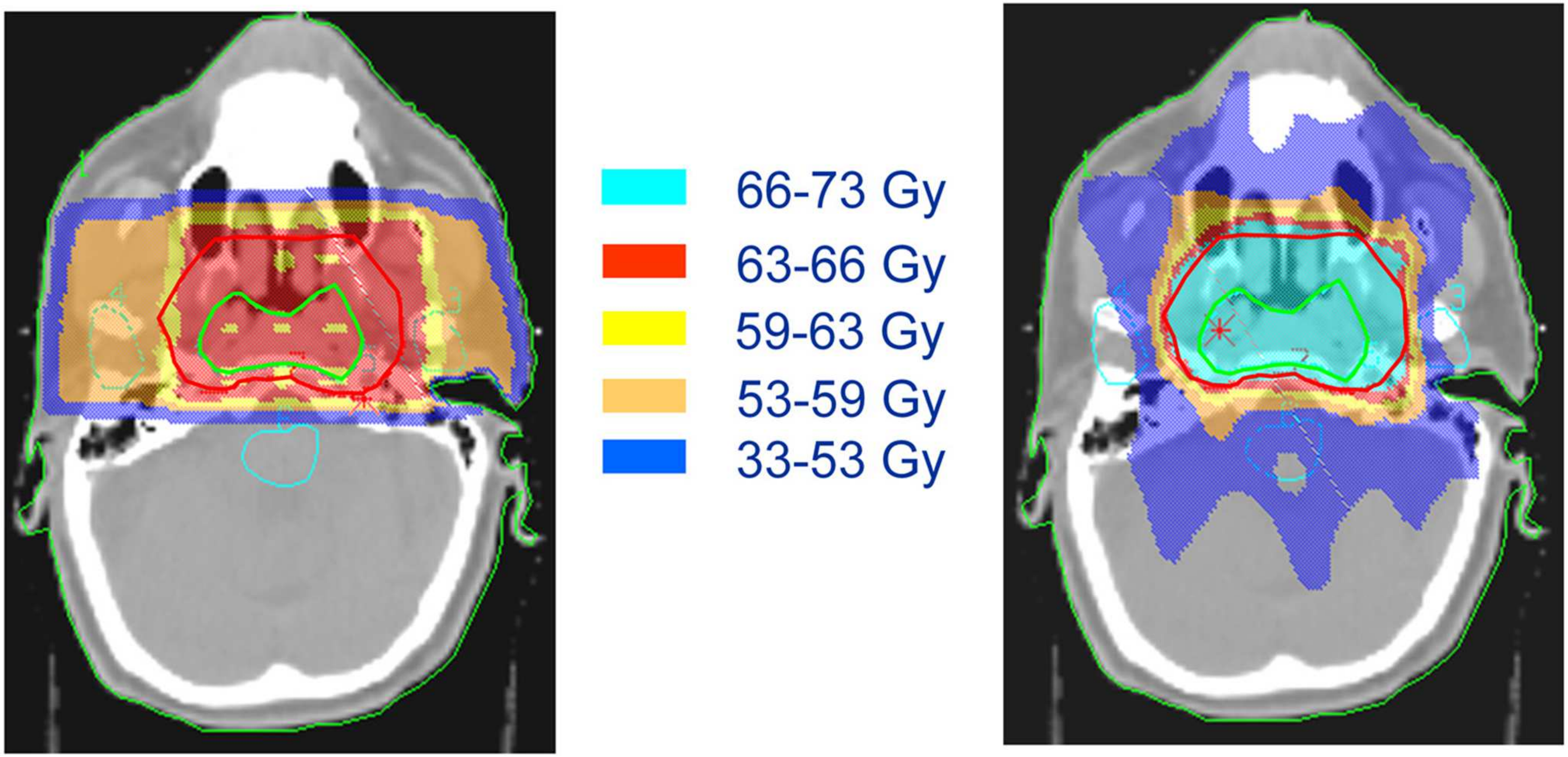
BEV projection from different angles



Typical 3D-CRT dose distribution



Dosimetric comparison of simple 2D-RT with complex multi-field 3D-CRT



3-field 2DRT

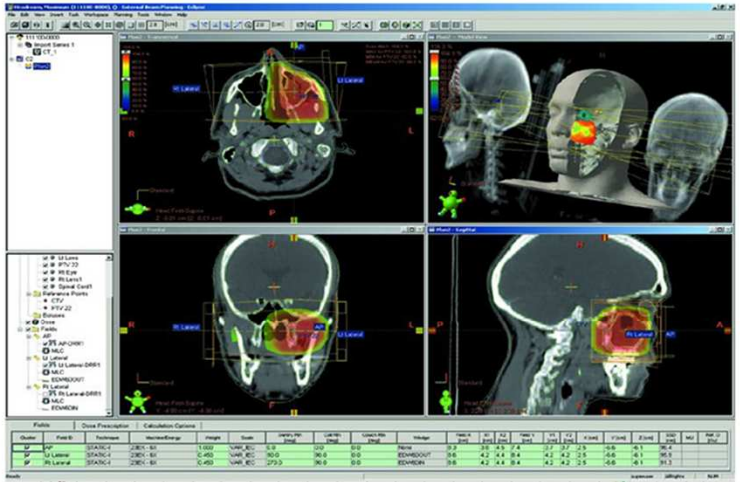
7-field 3DCRT

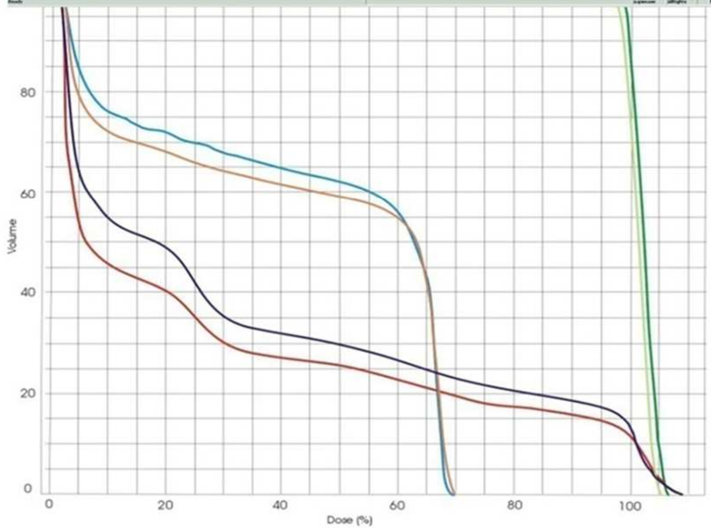
Plan evaluation

- Evaluate dose uniformity in the target. Check if the stated plan goals for hot spots and target coverage satisfied

- Evaluate plan using DVH, and examine dose distribution on every slice

- If necessary, adjust weights of beam and repeat dose calculation process to generate the optimal plan



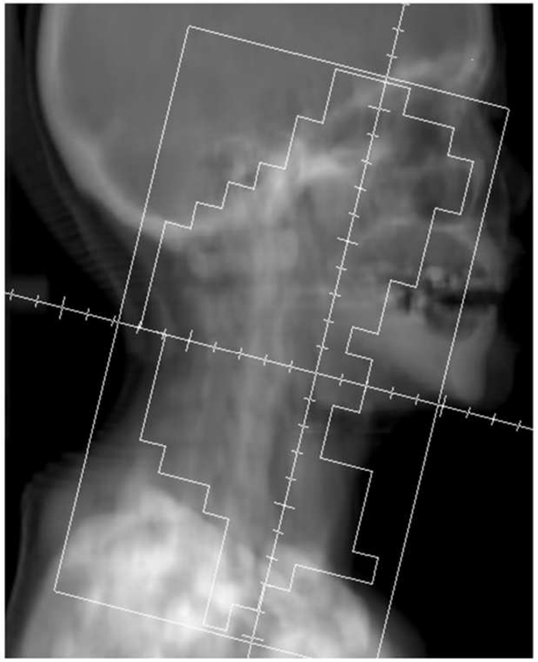


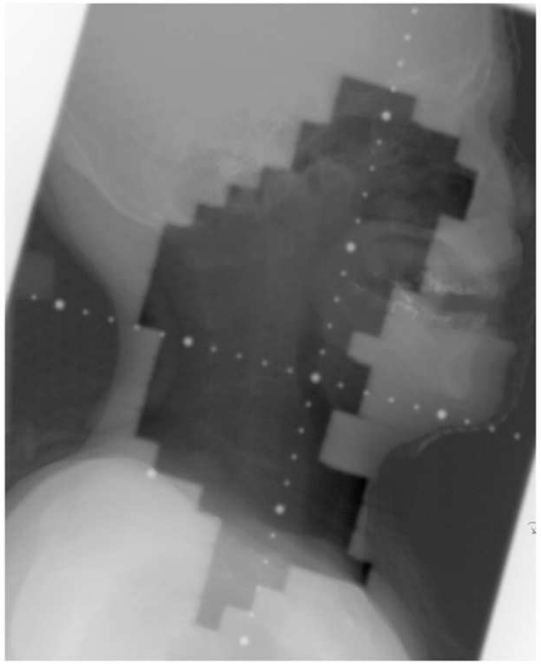
Plan approval & transfer

- Approve final plan
- Determine monitor unit settings
- Verify monitor unit calculation manually or with secondary calculation software, if available

Delivery verification

- Port film or EPID to verify isocenter placement as well as beam shape determination prior to start of treatment





Crucial & important step in conformal radiotherapy

Potential limitations of conformal radiotherapy

- Sophisticated treatment and planning procedures: Need appropriate technology and expertise
- Good understanding of cross-sectional anatomy and natural behaviour of disease: What is not contoured is not treated
- Need for stringent QA procedures to ensure accurate treatment planning and delivery
- More difficult to verify non-perpendicular beam arrangements
  - Usual anatomical landmarks are lost

Potential limitations of conformal radiotherapy

- Higher integral dose- Higher probability of radiation induced secondary cancer in the irradiated volumes. Requires long term follow up to show the effect
- Higher cost & staff time
  - Contouring of target and OAR
  - Planning and plan evaluation
  - QA

Procedure step	3D CRT median time in min (IQR[*])	Median person-hours
Orfit making	16.0 (12.8–19.0)	0.8
Planning scan	16.0 (13.5–19.0)	0.8
Contouring	187.5 (165.0–296.5)	3.1
Contouring approval	87.5 (55.0–142.0)	1.5
Planning	312.0 (193.8–411.3)	5.2
Plan approval	112.5 (80.0–170.0)	3.7
Plan implementation	49.0[‡] (38.0–54.3)	1.7[‡]
Quality assurance	–	–
Daily treatment time	15.2 (14.5–16.1)	0.6
Total treatment time	534.5 (507.3–566)	17.8
Overall time for the entire process	1496.5 (1274.5–1589.0)	37.3
Beam on time per fraction	1.1 (1.0–1.1)	–
Monitor units per fraction	316 (284.8–339.5)	–

Summary of differences between 2D-RT & 3D-CRT

Key Steps	Typical Procedures	
	2DRT	3DRT
Patient assessment & decision to treat with curative radiation therapy	• Clinical procedures	• Clinical procedures
Patient positioning & Immobilization	• Establish treatment position • Construct patient immobilization device	• Establish treatment position • Construct patient immobilization device • Mark reference marks/coordinate system patient or immobilization cast
Image acquisition	• Fluoroscopy • Single CT slice in treatment position	• CT, MR, PET and input into TPS system
Target & organ contouring	• Concept non-existant	• Image registration • Contour target volumes on CT slices • Contour OARs on CT slices
Dose prescription	• Prescription in midplane or at isocentre	• Specify dose prescription for PTV • Specify dose tolerances for OARs

Summary of differences between 2D-RT & 3D-CRT

Key Steps	Typical Procedures	
	2DRT	3DRT
Beam design & arrangement	• Regular fields/ blocks	• Design beam arrangements based on BEV • Design field shape (blocks, MLC) • Determine beam modifiers • Determine beam weighting
Dose calculation	• Fill in the blanks	• Select dose calculation algorithm and calculation grid • Input dose prescription • Perform dose calculation • Set relative & absolute dose normalizations
Plan evaluation and optimization	• Usually in a single plane	• 2D & 3D isodose displays • DVH analysis • Iterate beam arrangement, modifiers • Calculate MU for each beam

Summary of differences between 2D-RT & 3D-CRT

Key Steps	Typical Procedures	
	2DRT	3DRT
Plan approval	• Based on a single slice	• Perform overall review of all aspects of plan • Plan approval by Oncologist • Generate hardcopy output
Generation of QA data	• Weekly chart reviews/ at best weekly port films	• Generate DRRs for QA • Generate of phantom plan for QA
Treatment data file transfer to treatment machine	• Manually	• Upload treatment parameters to record and verify system • Verify transferred treatment parameters to treatment machine • Verification simulation
Treatment simulation	• Conventional simulator	• Simulate & verify the treatment plan
Treatment delivery	• Treatment delivery	• Field portal verification & other QA checks • Treatment delivery • In vivo dose monitoring

3D-CRT summary

- Field design is based on BEV projection of the target volume
- Volumetric dose calc
- Volumetric plan evaluation tools such as DVH
- Uniform radiation intensity across the field
- Conformity of dose distribution to the target volume

3D-CRT process & workflow summary

Patient Immobilization → Planning Imaging CT/MR/PET → Contour Target Volume and Normal Structure → Select Beam Geometry and Energy

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Forward Planning Optimization

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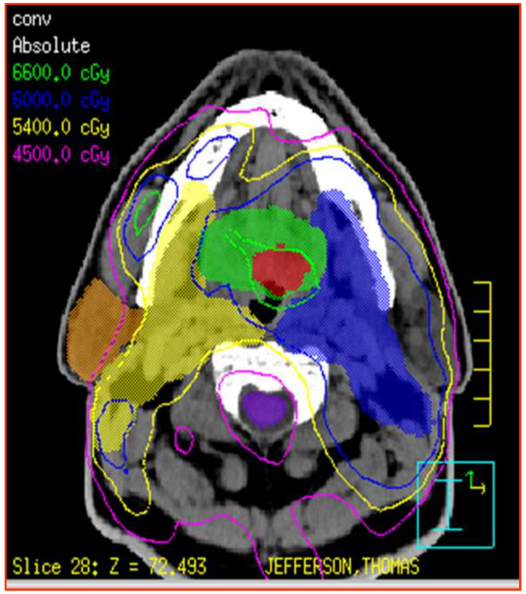
Plan Evaluation & Approval

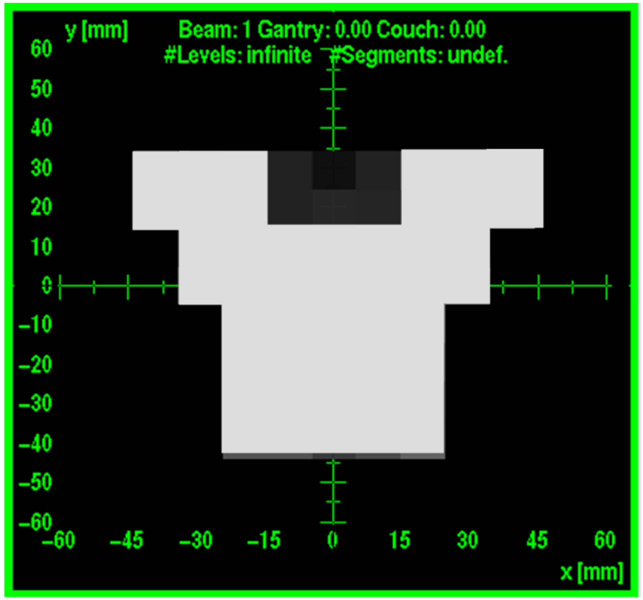
↓

Patient Set up

↓

Patient Treatment → Patient Position Verification → Patient Dose Verification → Machine QA





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MISSION

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