In-Room Radiographic Imaging for Localization

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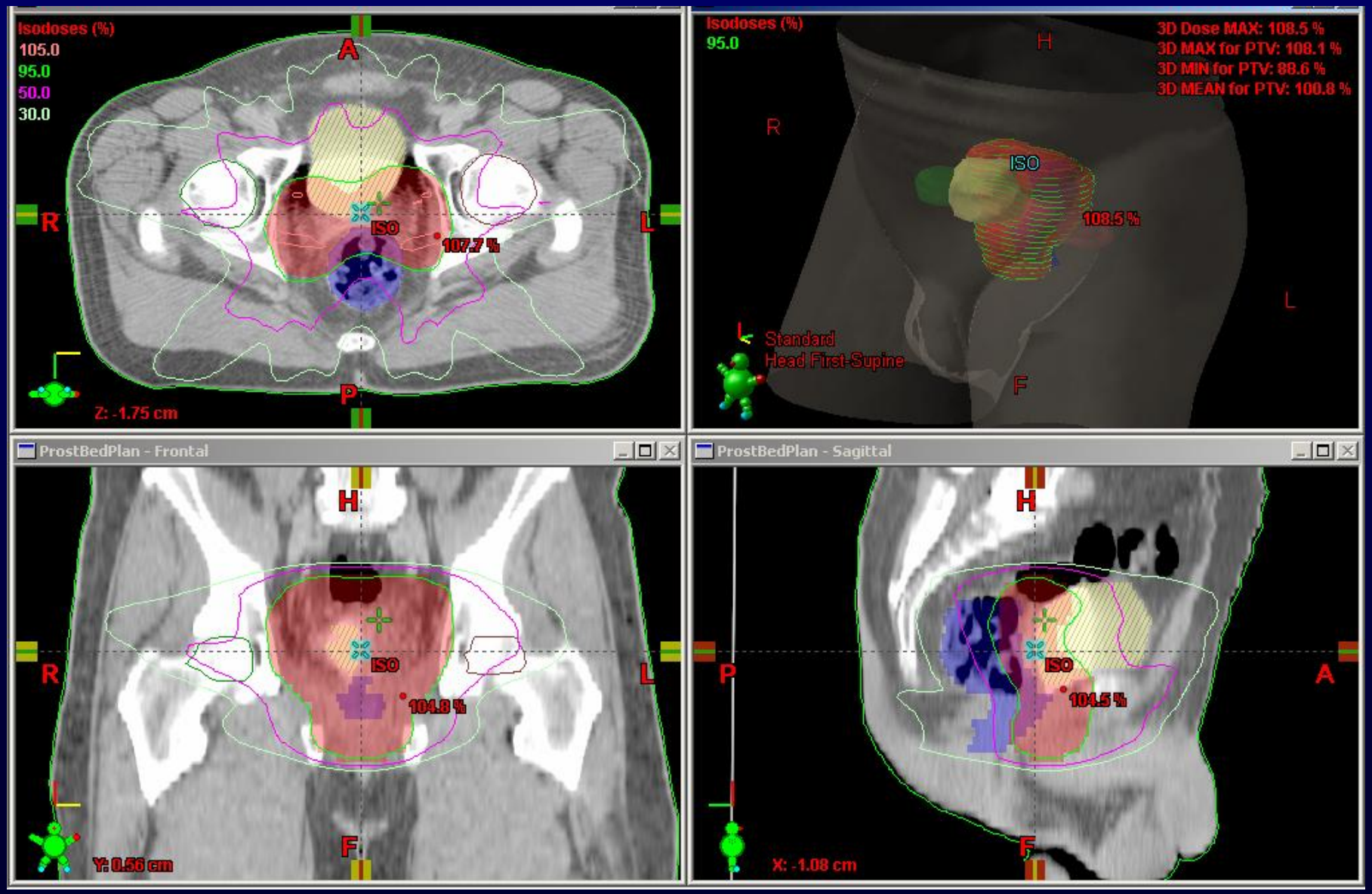
Acknowledgements

- Invitation from organization committee
- Members of Radiation Oncology Department at Duke University Medical Center
- Duke University Medical Center has a master research agreement with Varian Medical Systems

Outlines of the Talk

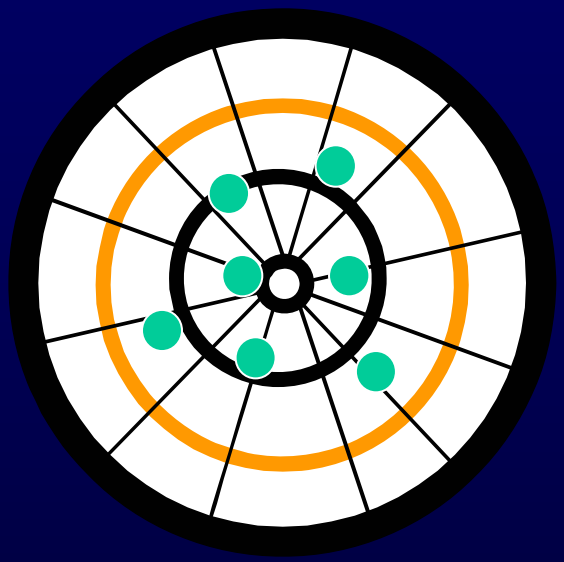
- Introduction
- Imaging Method
- Clinical Applications
- Special Considerations
- Summary

Why In-Room – Prostate IMRT Case



Why In-Room: H&N Case

Why In-Room: Improving Precision and Accuracy

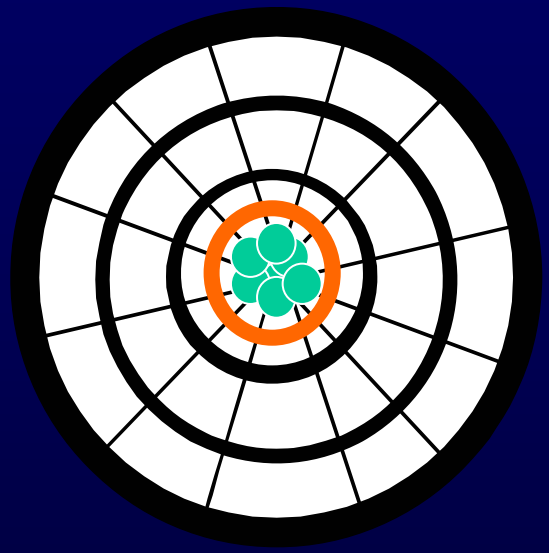


Accurate but not precise

IGRT

Precise but not accurate

IMRT



Precise and accurate

IGRT+IMRT

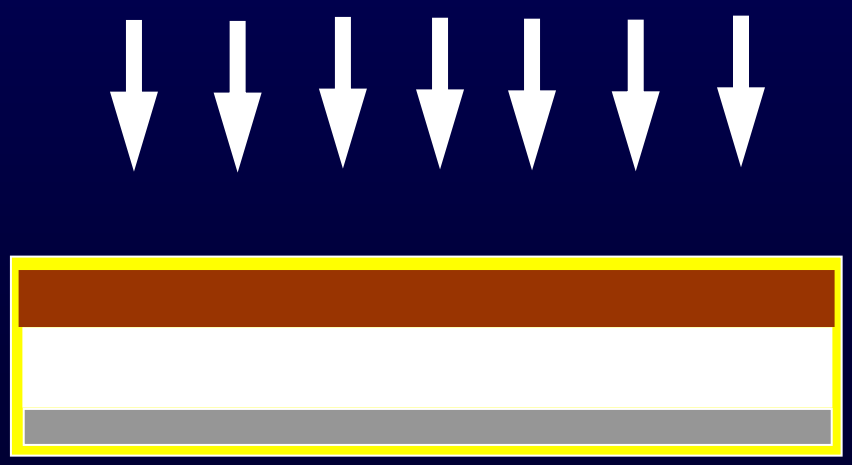
Yin et al Sem Rad Onc 2006

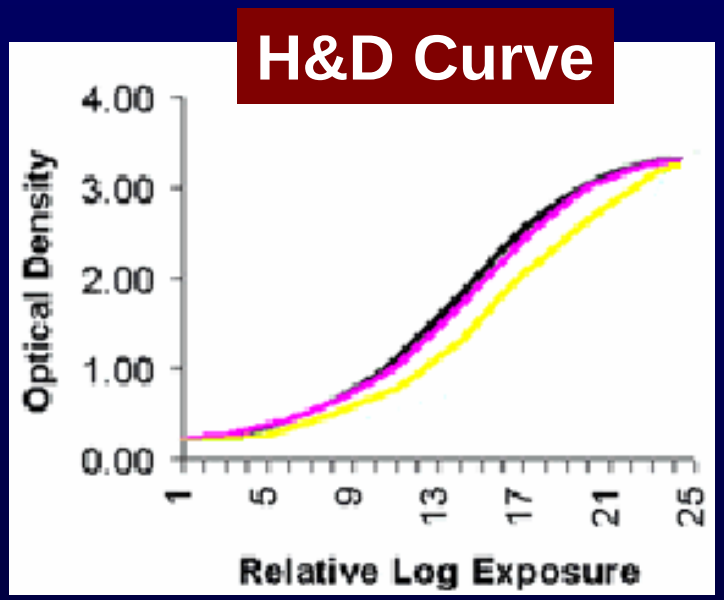
Imaging Methods

- **Film Imaging**
- **Computed Radiography Imaging**
- **Digital MV X-ray Imaging**
- **Digital kV X-ray Imaging**
  - ***Room-Mounted System***
  - ***Gantry-Mounted System***
  - ***Mobile Systems***
- **Tomographic Imaging**
  - ***On-board CBCT***
  - ***On-board Digital Tomosynthesis (DTS)***

Imaging Method: Film Imaging

Imaging principle





Metal sheet → produce electrons
Screen → convert to light
Film → image

Examples of Film Imaging Systems

The Kodak EC-L film system
EC film + Kodak EC-L oncology cassette (or a Kodak EC-L fast cassette)

The Kodak simulation film system
Kodak simulation film and Kodak Lanex regular screens (green sensitive)

Kodak EC-V Verification System for Portal Imaging
Kodak EC film or Kodak EC-V verification cassette

Kodak Portal Pack for Localization Imaging
READY-PACK Packaging with or without a metal screen cassette

Kodak X-OMAT V Film and Cassettes
Used for verification imaging and dosimetry testing

Kodak EDR2 Film
READY-PACK Packaging

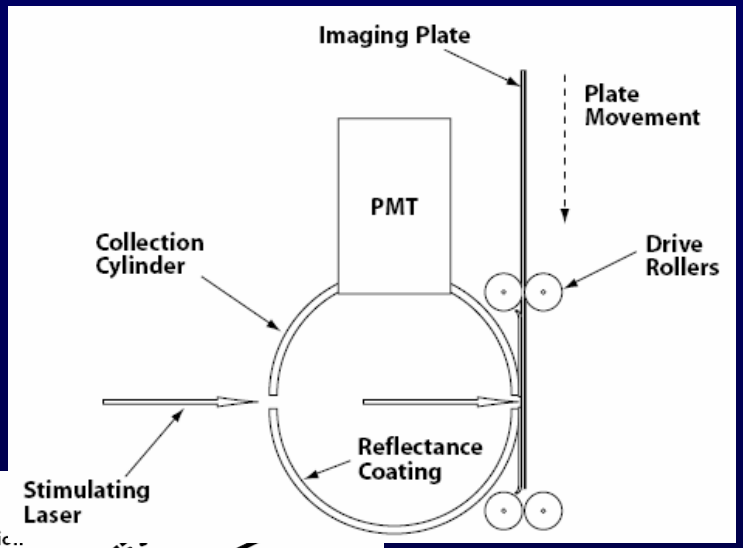
http://www.kodak.com/global/en/health/productsByType/onco/onco_Product.jhtml#products

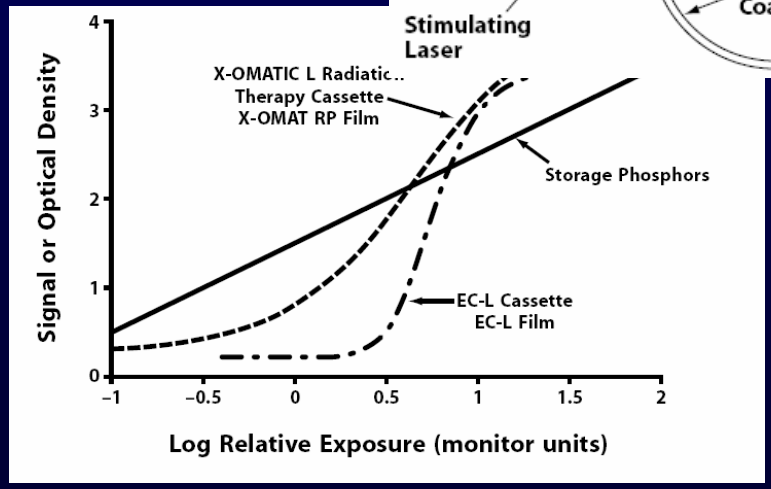
Examples of Film Imaging Systems

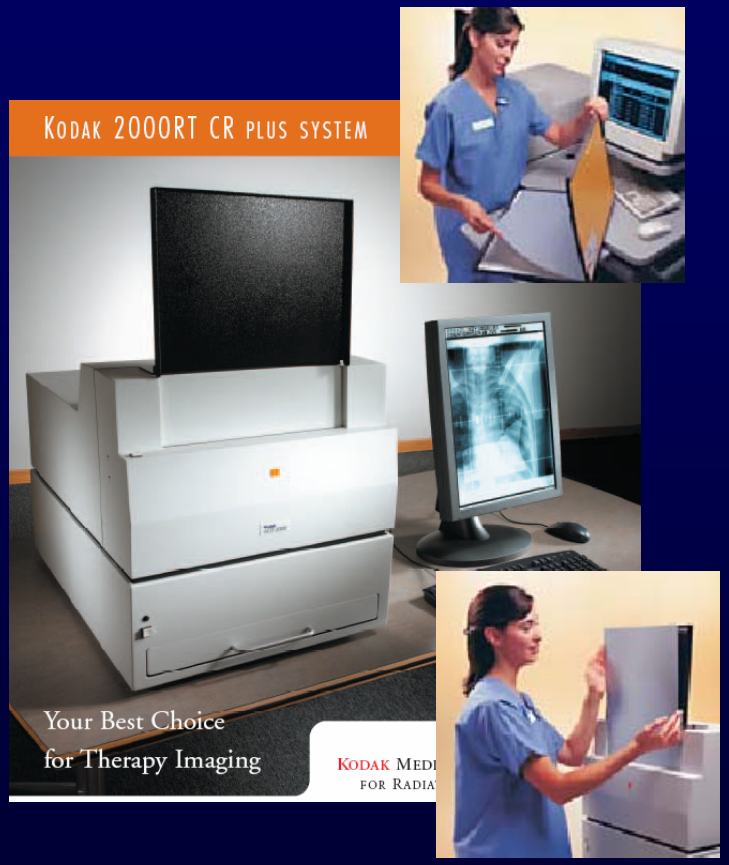
FILM	RESPONSE RANGE	APPROXIMATE SATURATION EXPOSURE
KODAK Portal Pack for Localization Imaging (PPL)	0.25 - 5 cGy	10 cGy
KODAK X-OMAT V Film (XV-2)	5 - 100 cGy	200 cGy
KODAK Extended Dose Range Film (EDR2)	25 - 400 cGy	700 cGy

http://www.kodak.com/global/en/health/productsByType/onco/onco_Product.jhtml#products

Imaging Method: CR Imaging







CR imaging principle

CR for sim., loc., veri.

http://www.kodak.com/global/en/health/productsByType/onco/onco_Product.jhtml#products

Imaging Method: CR Imaging

CR - kV simulation image

CR - MV portal image

Digital MV X-ray Imaging

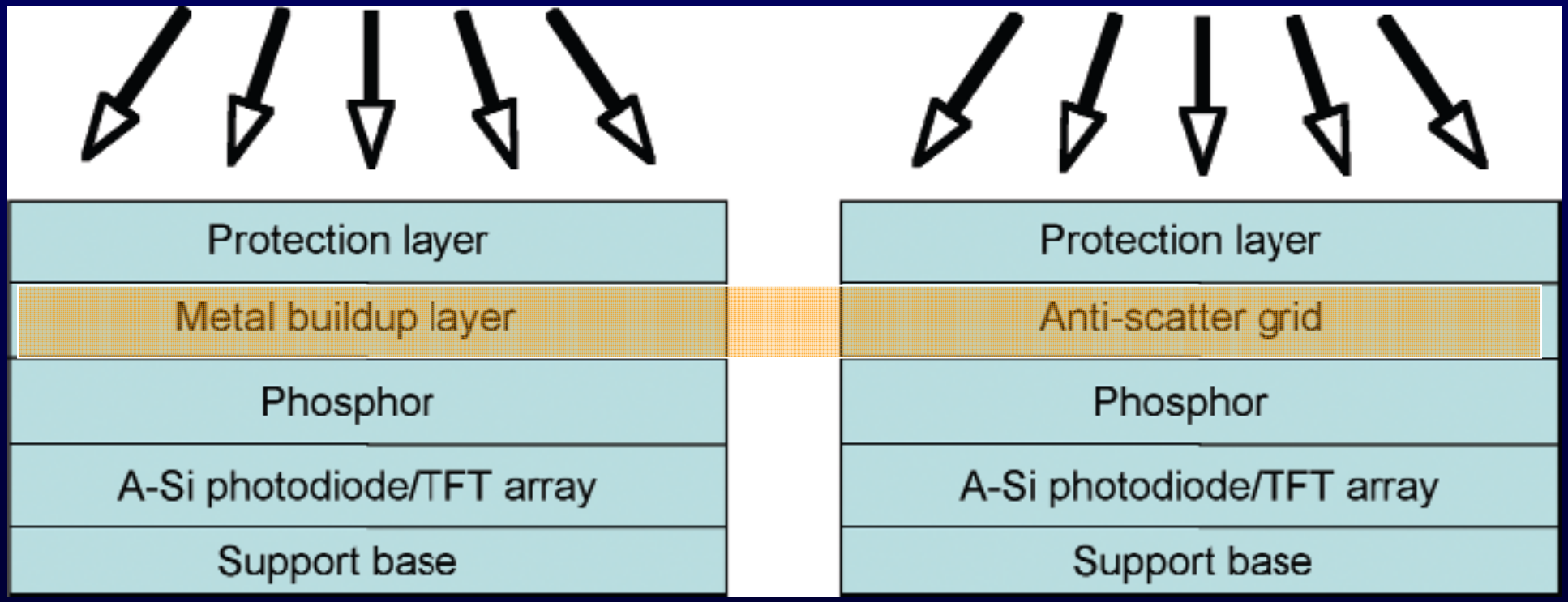
- Camera and scintillation screen based imagers
  - Incident x-rays interact with a metal plate and scintillation screen to produce visible light.
- Liquid ionization chamber system
  - the ionization behavior of the liquid and the performance of the readout electronics
- Amorphous Silicon (a-Si) technology

Digital kV X-ray Imaging

- **Digital kV X-ray Imaging**
  - ***Room-Mounted System***
  - ***Gantry-Mounted System***
  - ***Mobile Systems***

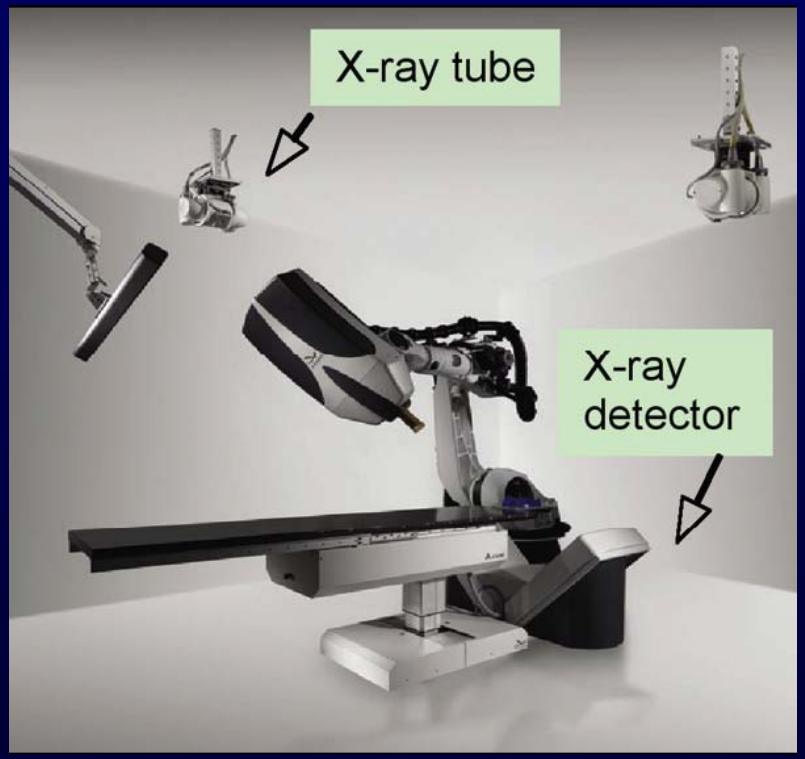
- **Amorphous Silicon (a-Si) technology**

a-Si Detector Configuration



MV imaging **kV imaging**

Room-Mounted X-Ray Systems



CyberKnife® imaging system Novalis® imaging system

Gantry-Mounted X-Ray Systems

Elekta Synergy® system

Varian Trilogy™ system

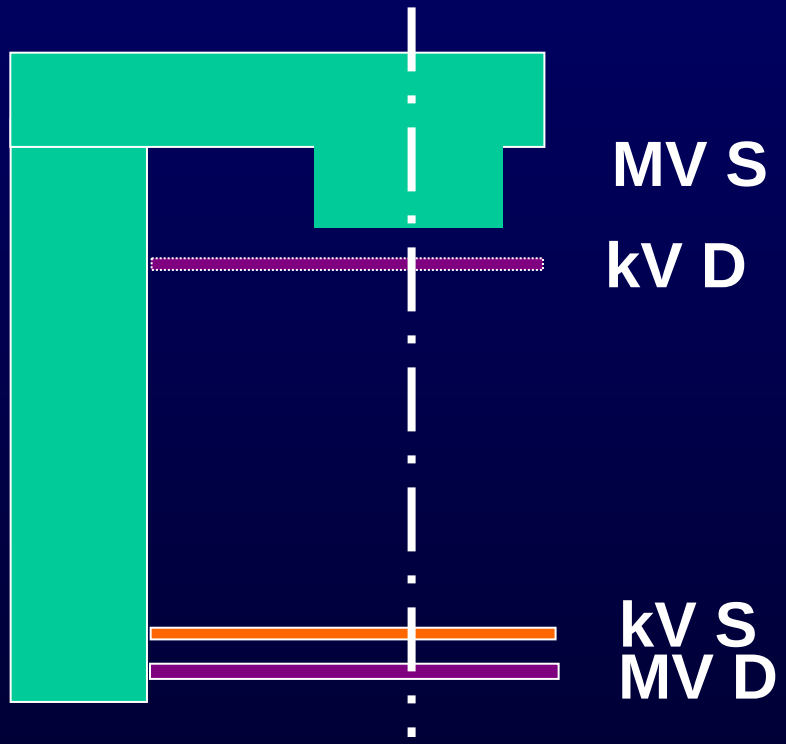
“Mobile” Systems

Varian ExaCT™ at MDACC

Siemens C-arm system

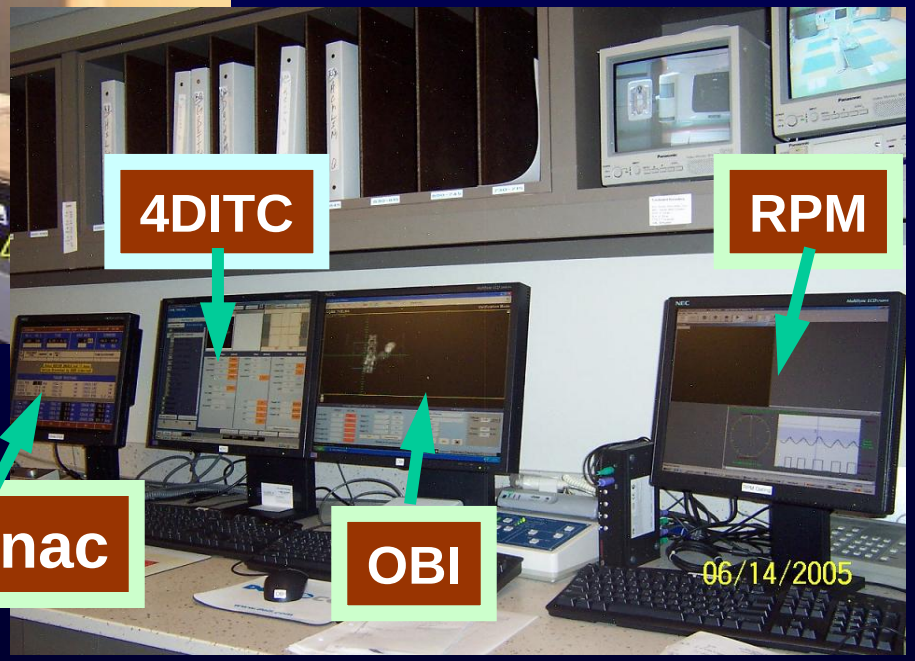
MV Tomographic Imaging

TomoTherapy Unit



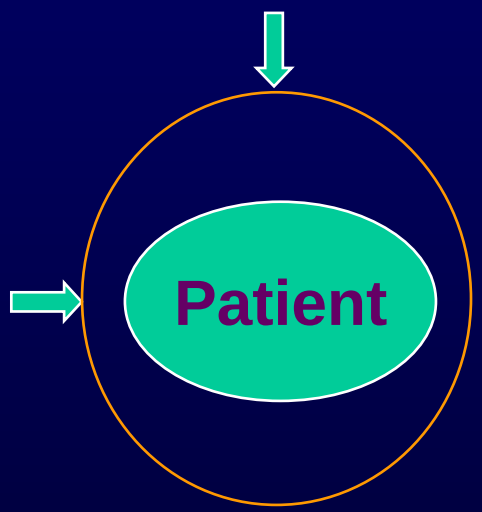
Siemens' system

Duke On-Board Imager (OBI)

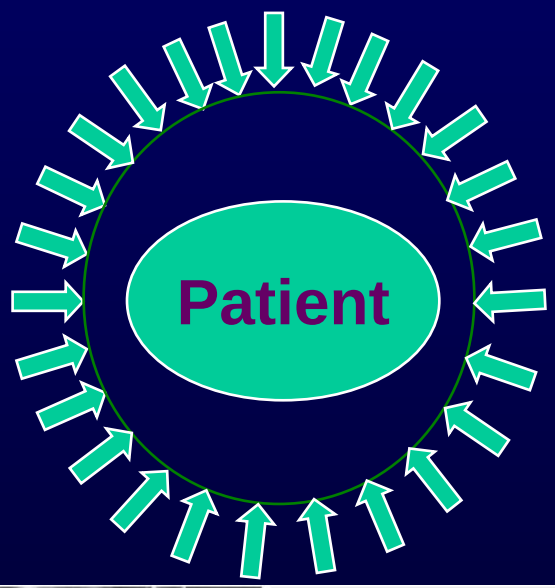


Radiographic Imaging Options

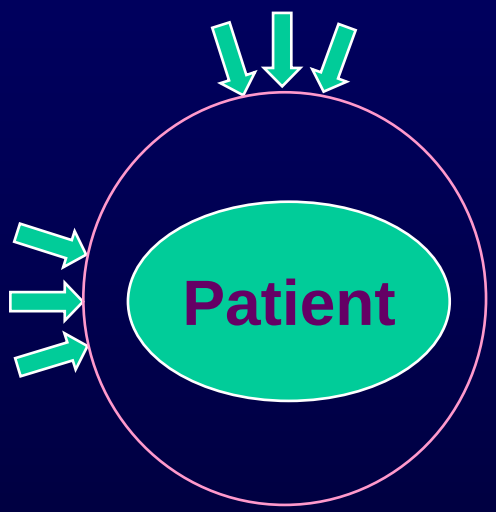
Orthogonal radiograph

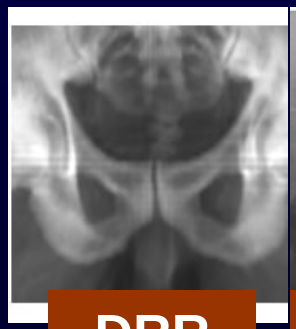


Cone-Beam CT (CBCT)

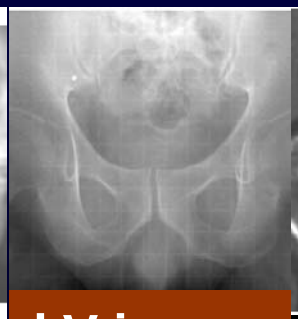


DTS - Digital TomoSynthesis



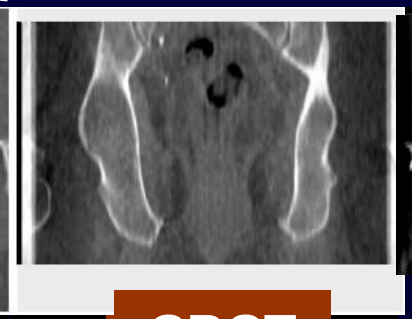


DRR



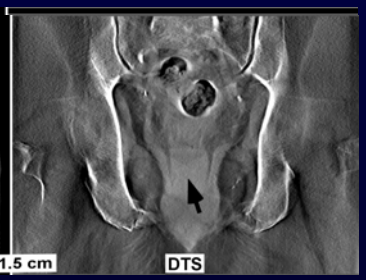
kV image

CT



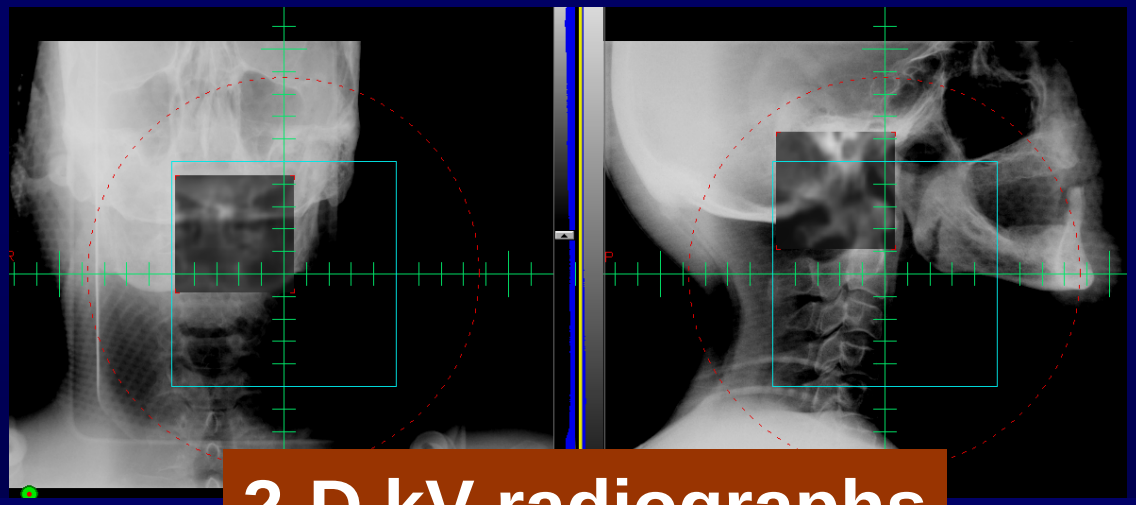
CBCT

RDTS

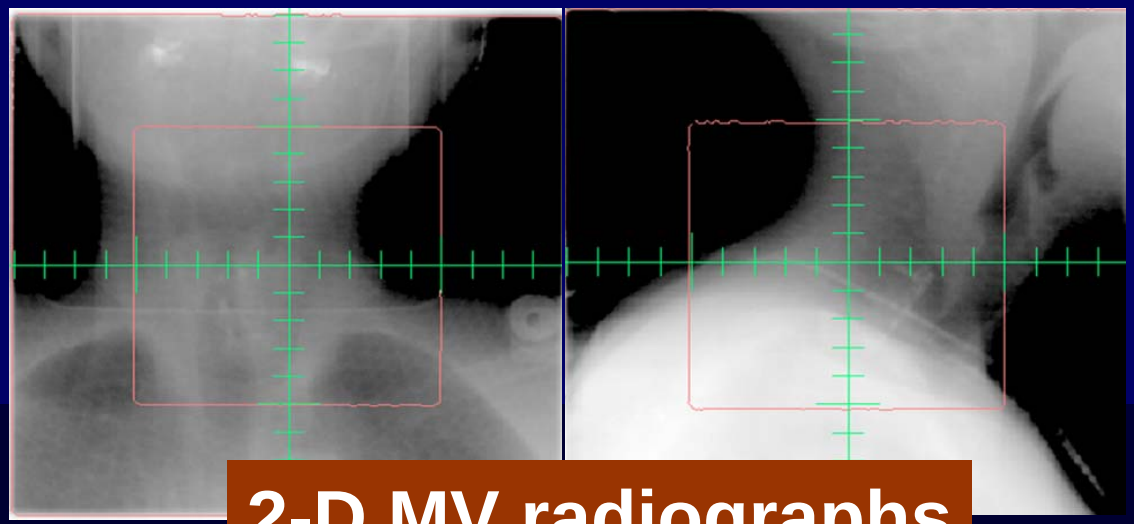


DTS

On-Board kV and MV Radiographs



2-D kV radiographs

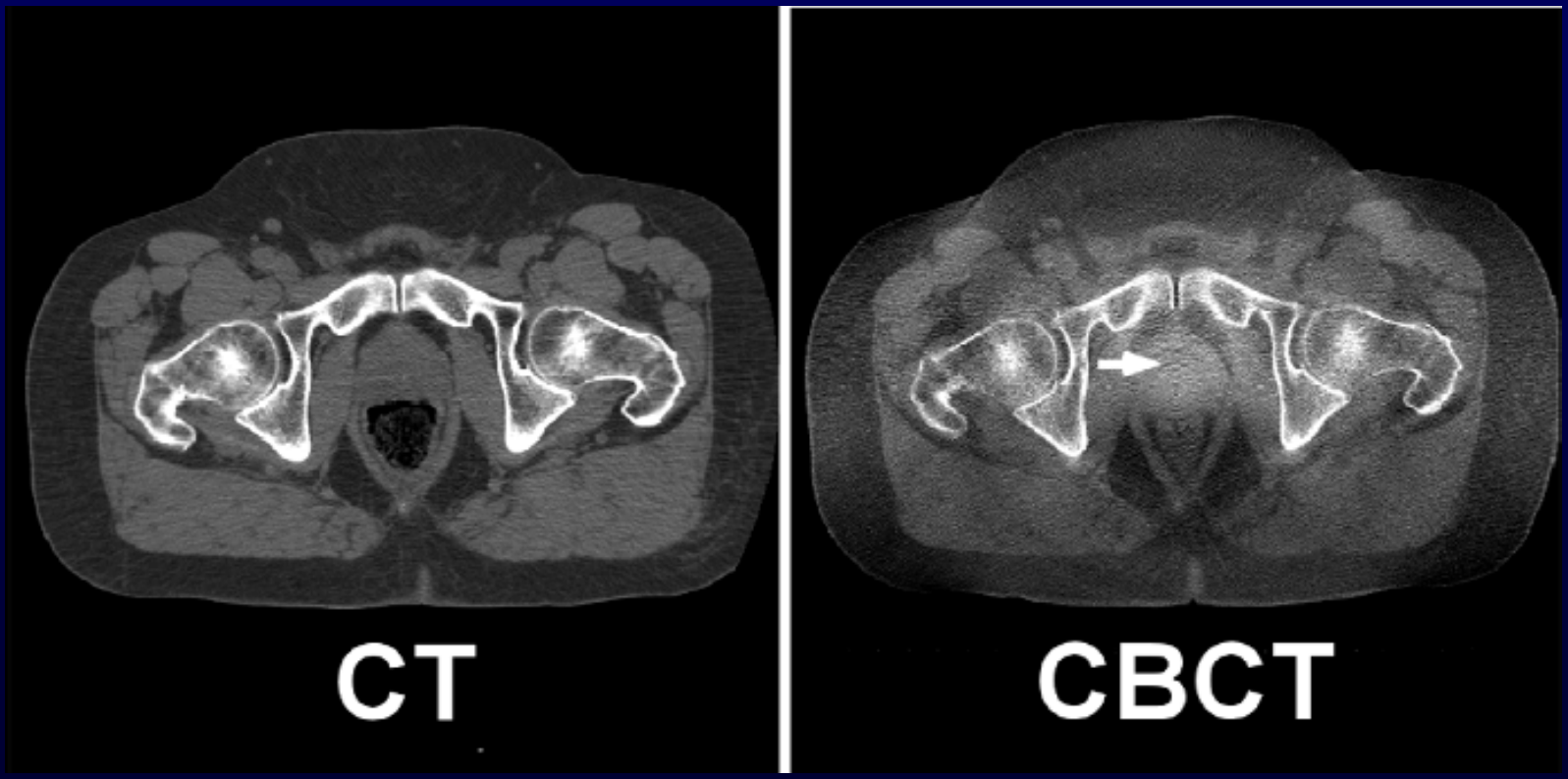


2-D MV radiographs

kV compared to MV:

- Better bone/soft tissue contrast
- Less radiation dose
- No metal artifacts
- Fluoroscopic imaging
- Not treatment beam
- Not real-time imaging

Tomographic Imaging:
On-board Cone-Beam CT (CBCT)

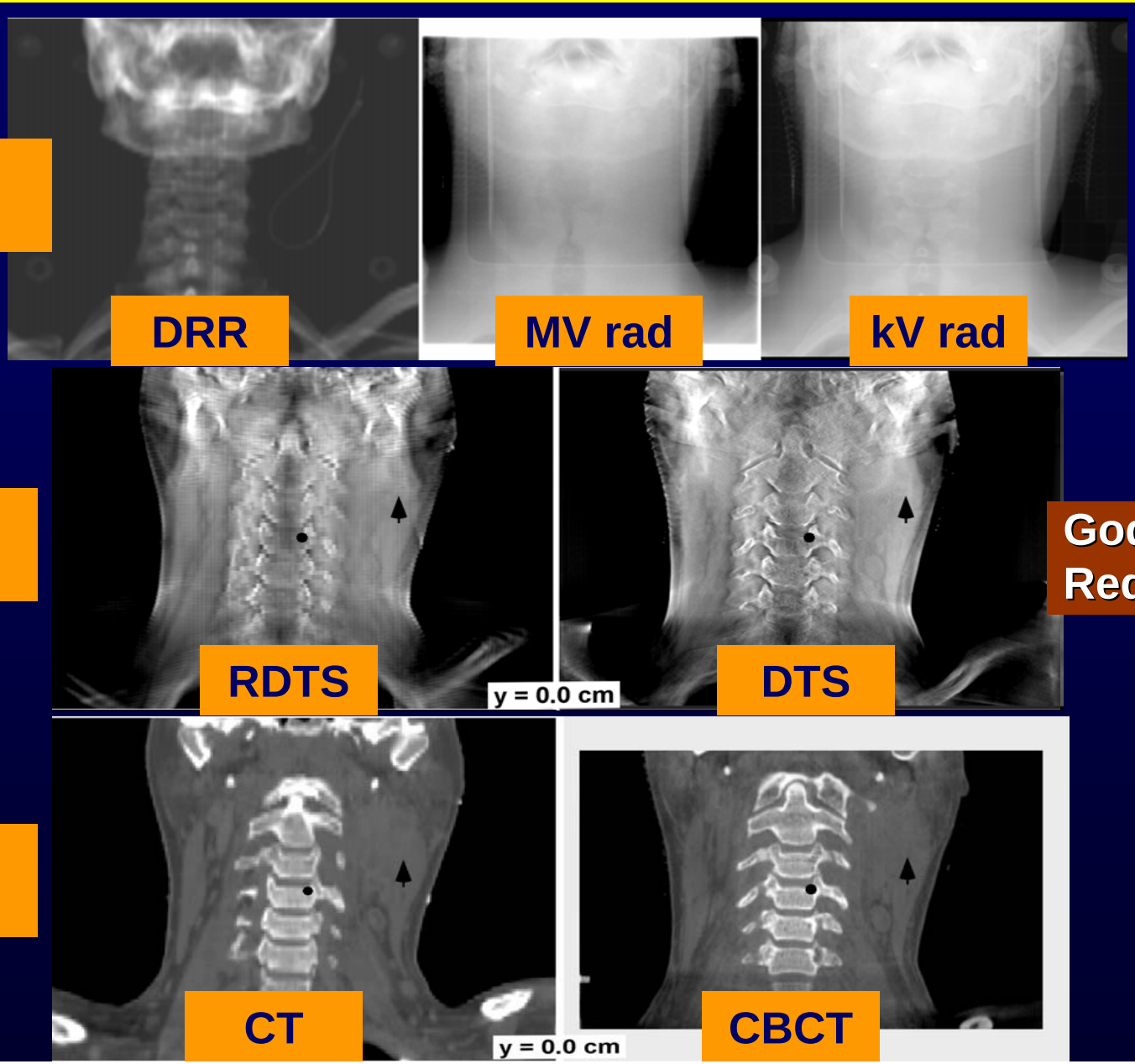


On-Board H & N DTS Imaging

0º

44º

360º



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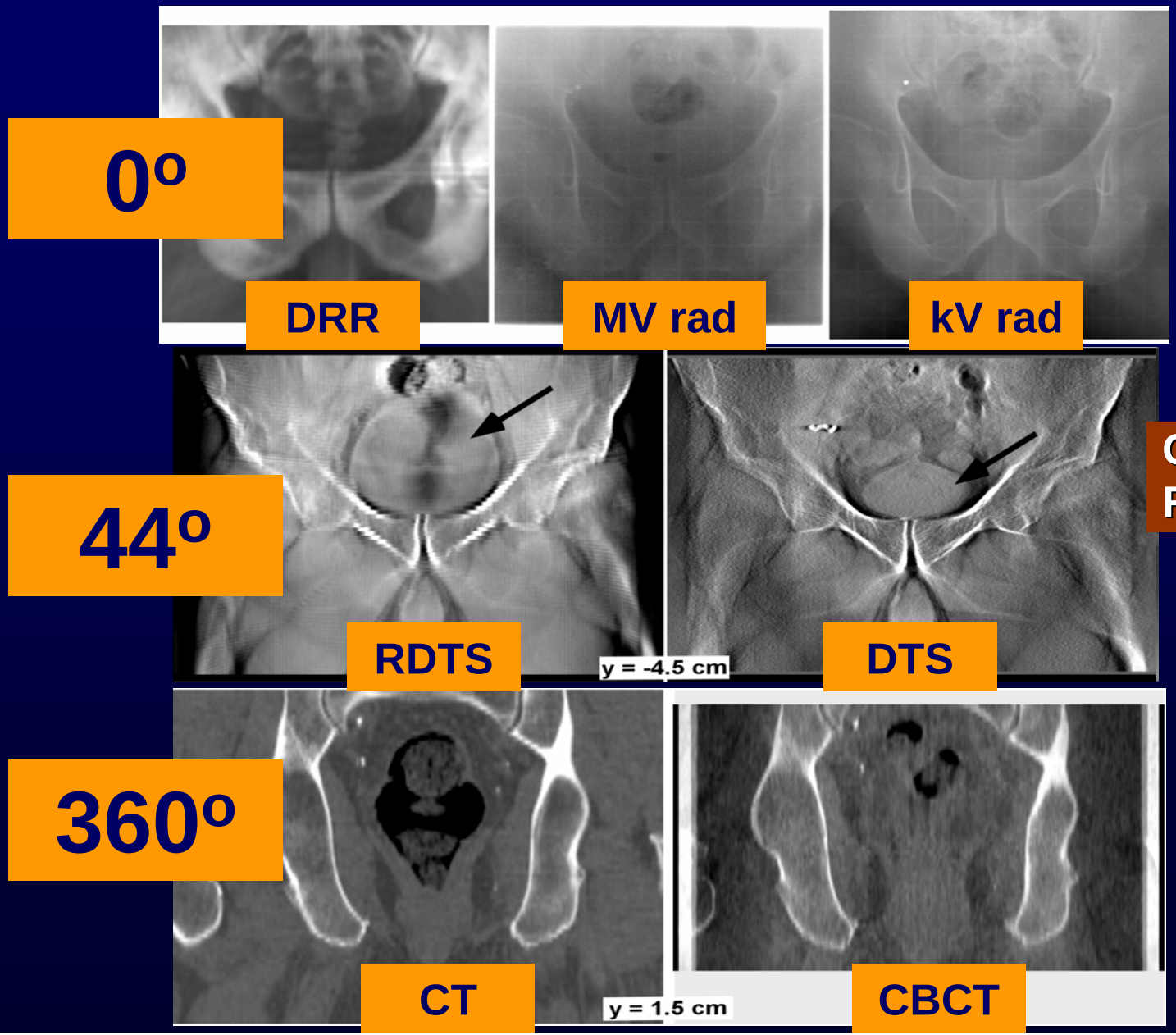
On-Board Prostate DTS Imaging



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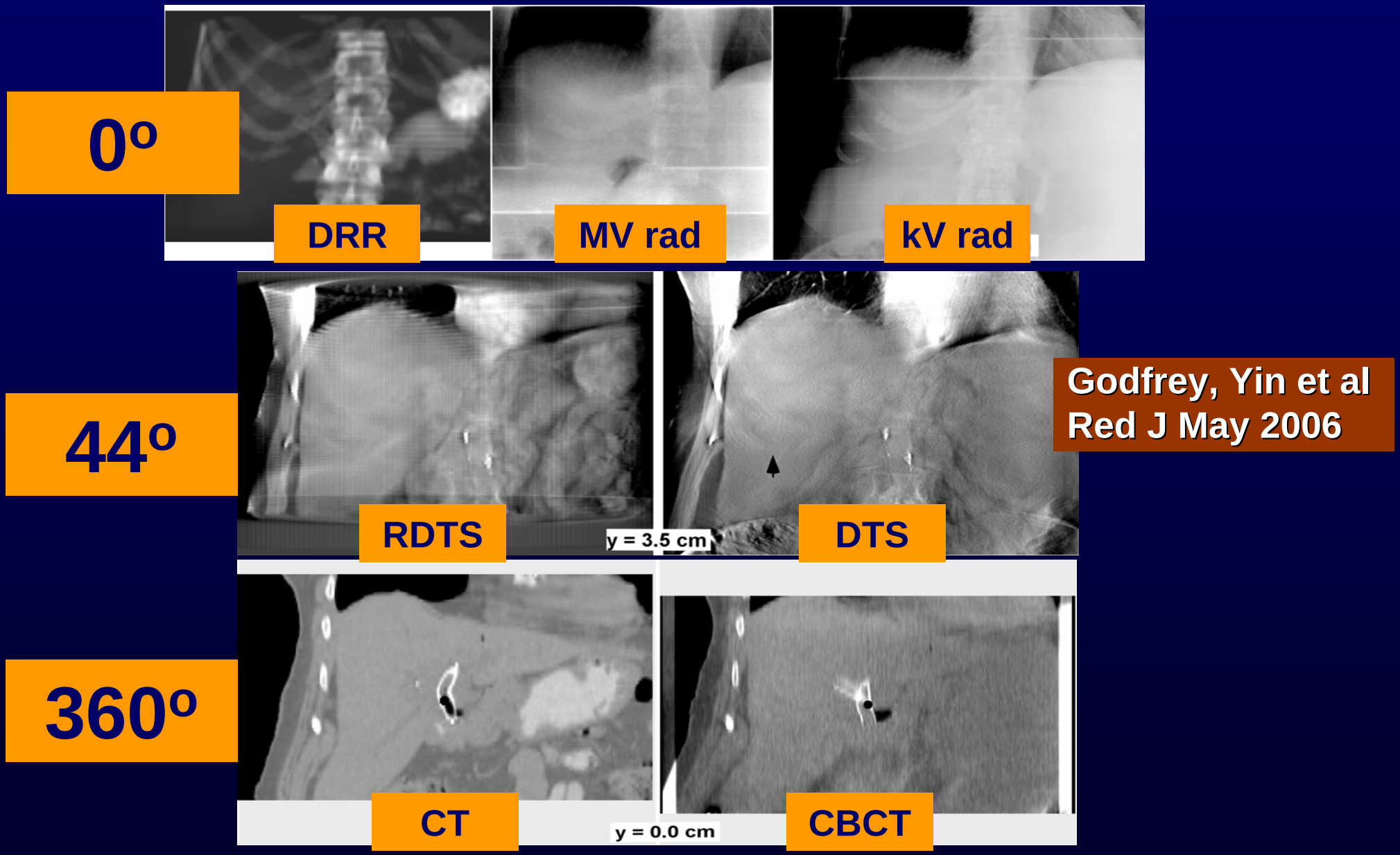
On-Board Liver DTS Imaging



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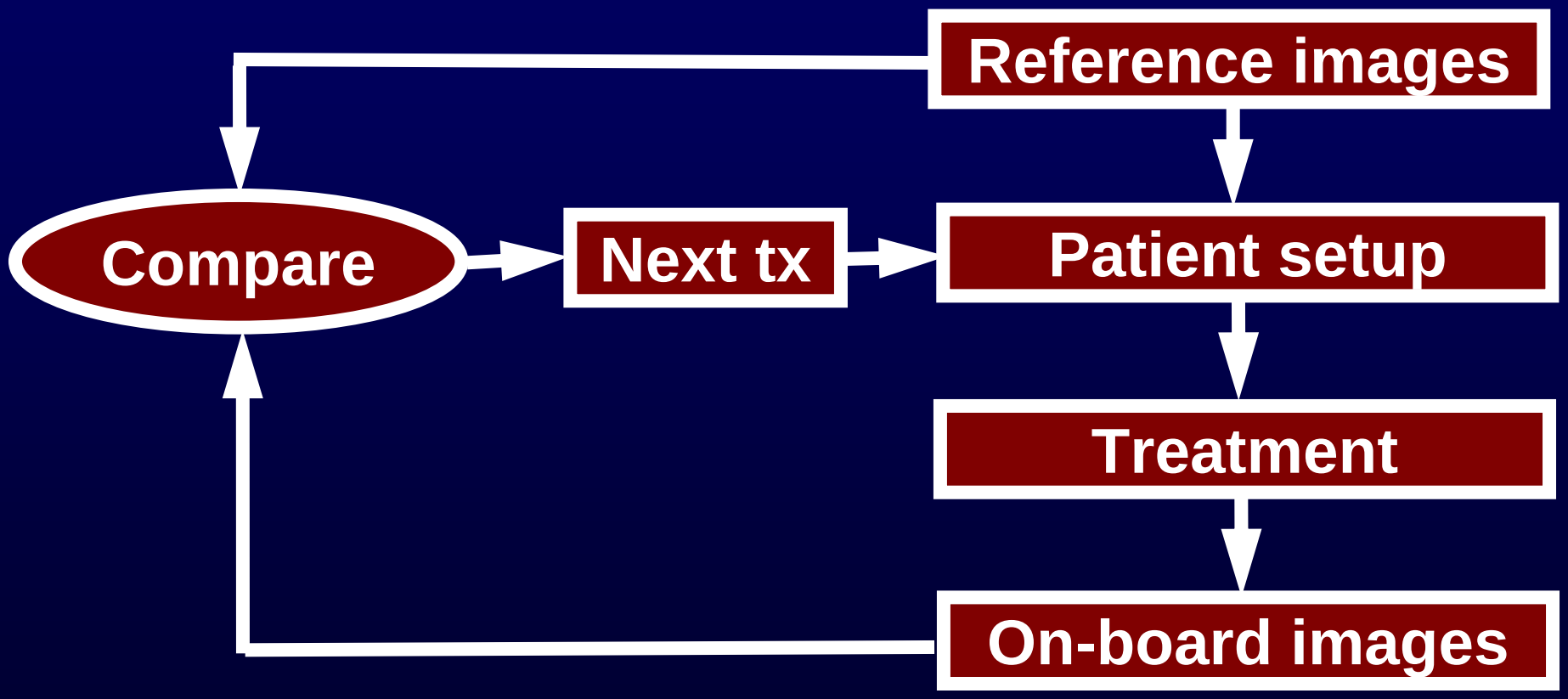
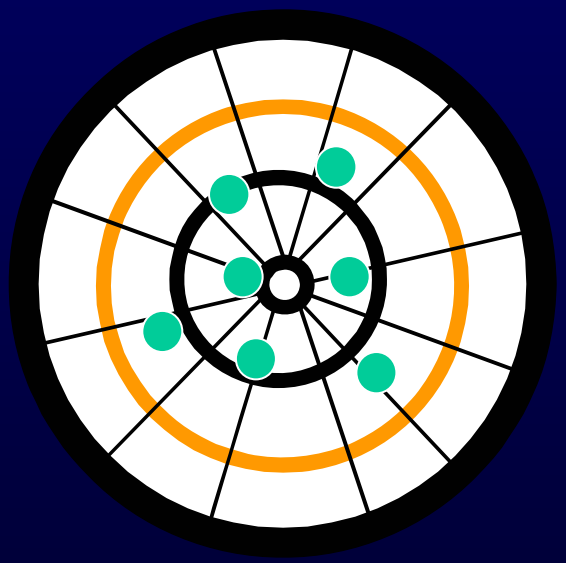
Clinical Applications

- **Off-line Correction**
  - ***Portal Verification***
  - ***Isocenter Verification***
- **On-line Correction**
  - ***kV-kV Localization***
  - ***kV-MV Localization***
  - ***MV-MV Localization***
  - ***CBCT-Guided Localization***
  - ***Image Fusion***
- **Imaging for Respiratory-gated Treatment**

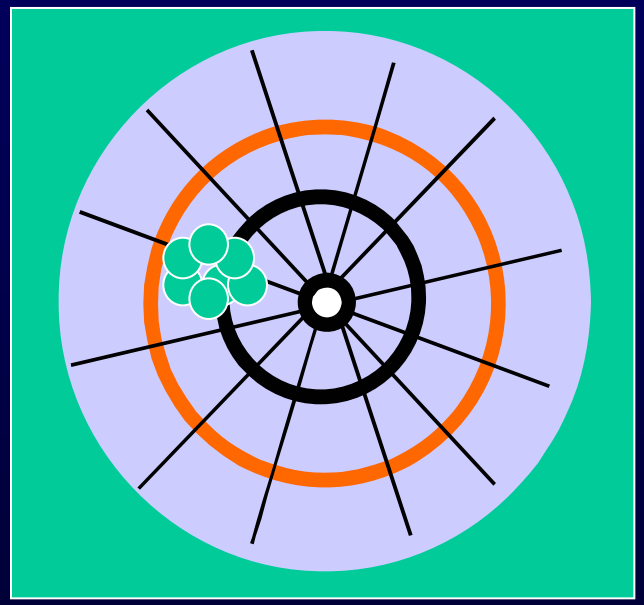
Off-Line Portal Verification



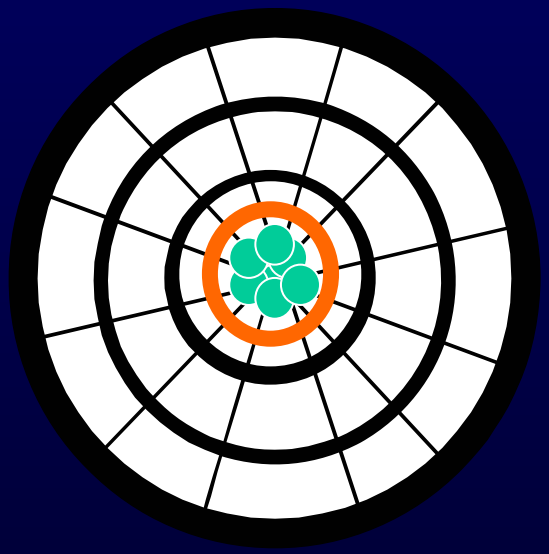
What Will Off-Line Verification Do for Precision and Accuracy?



Random error

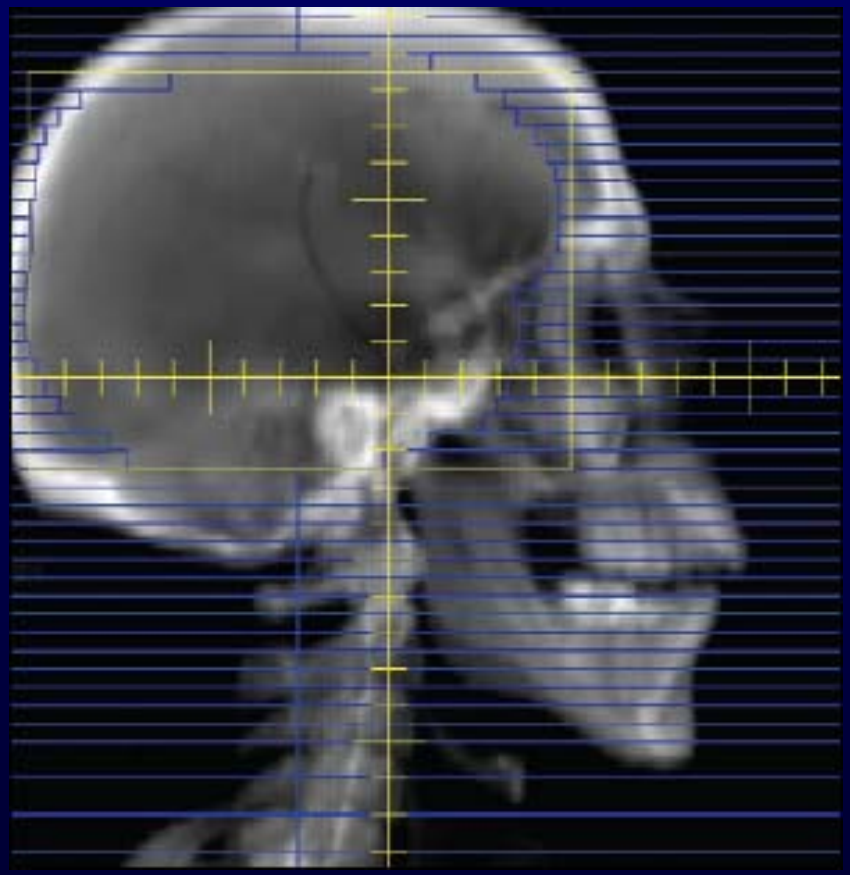


Systematic error

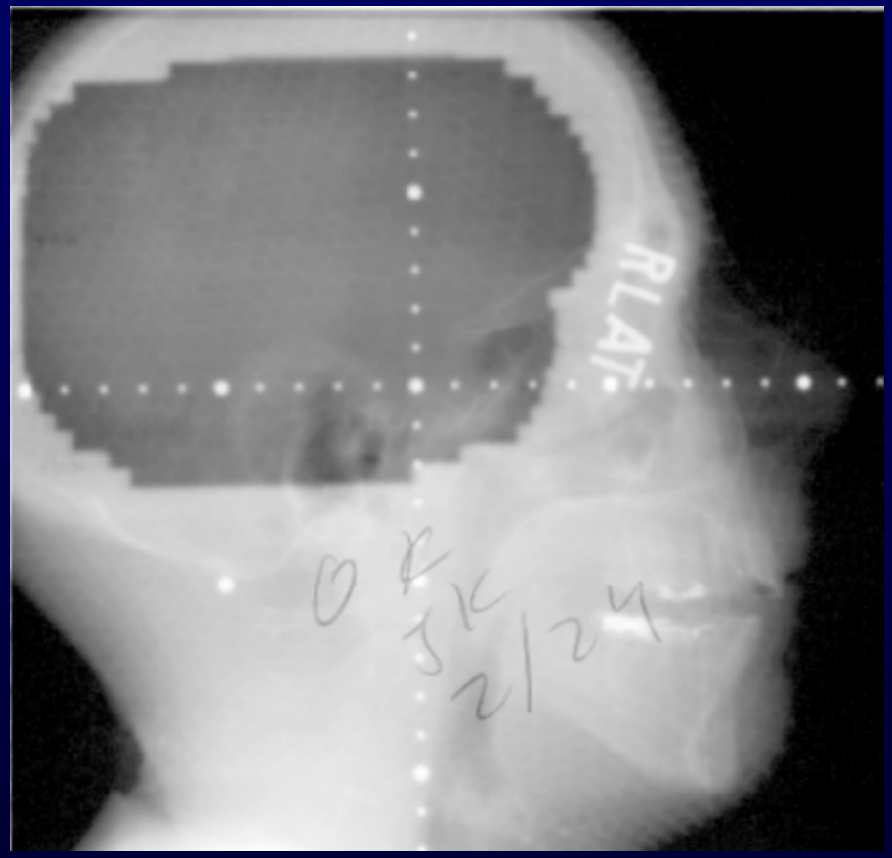


Systematic & Random error

Portal Field Verification

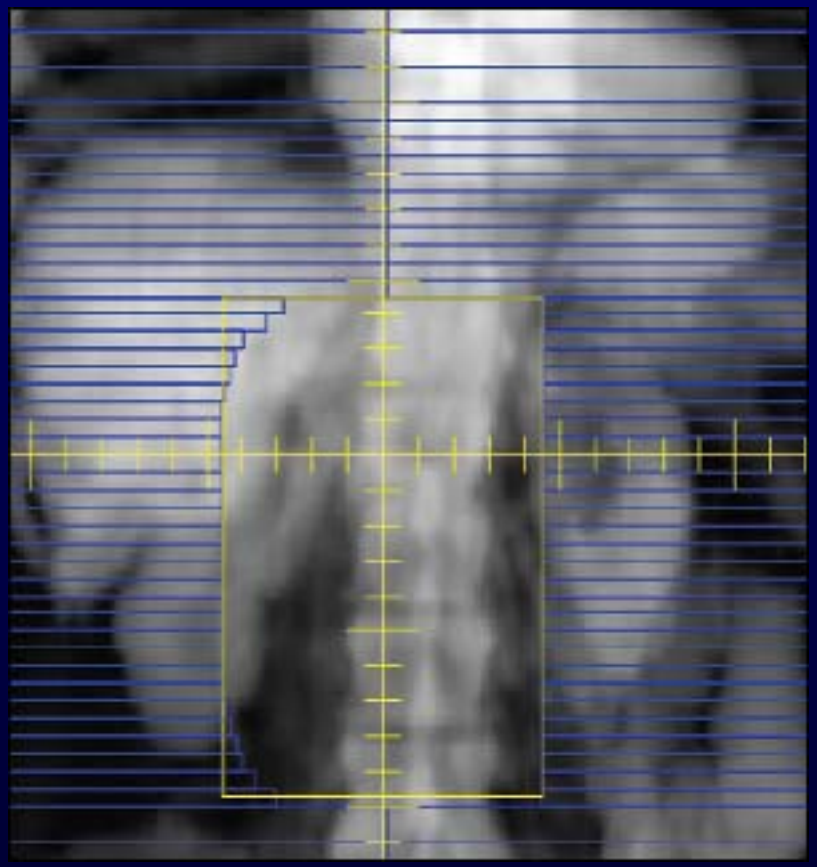


Reference image



Portal image

Portal Field Verification



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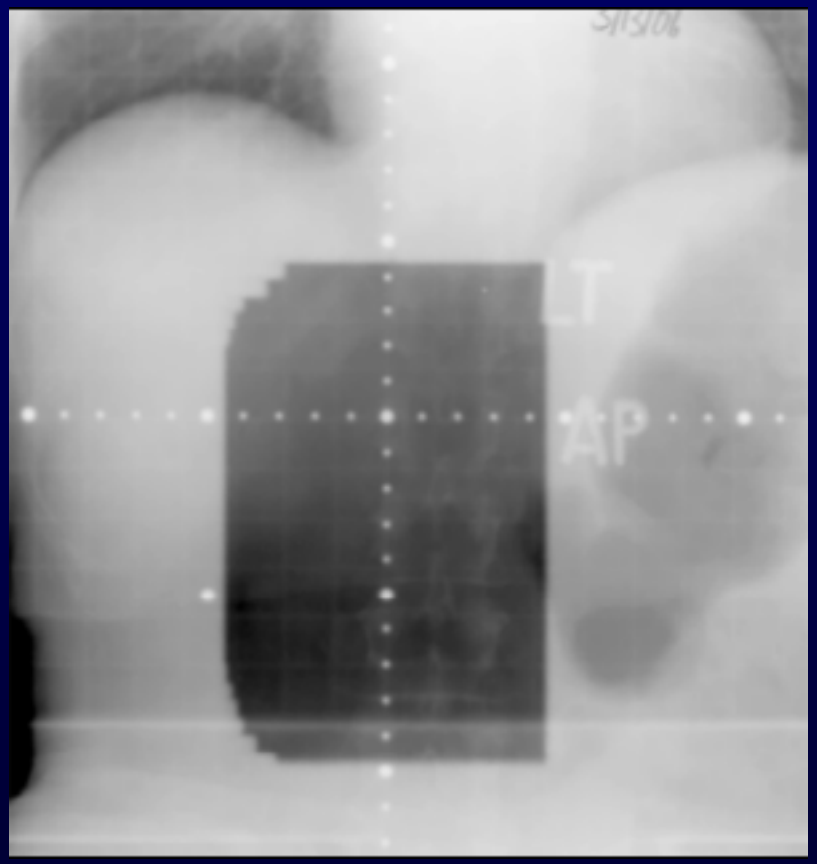
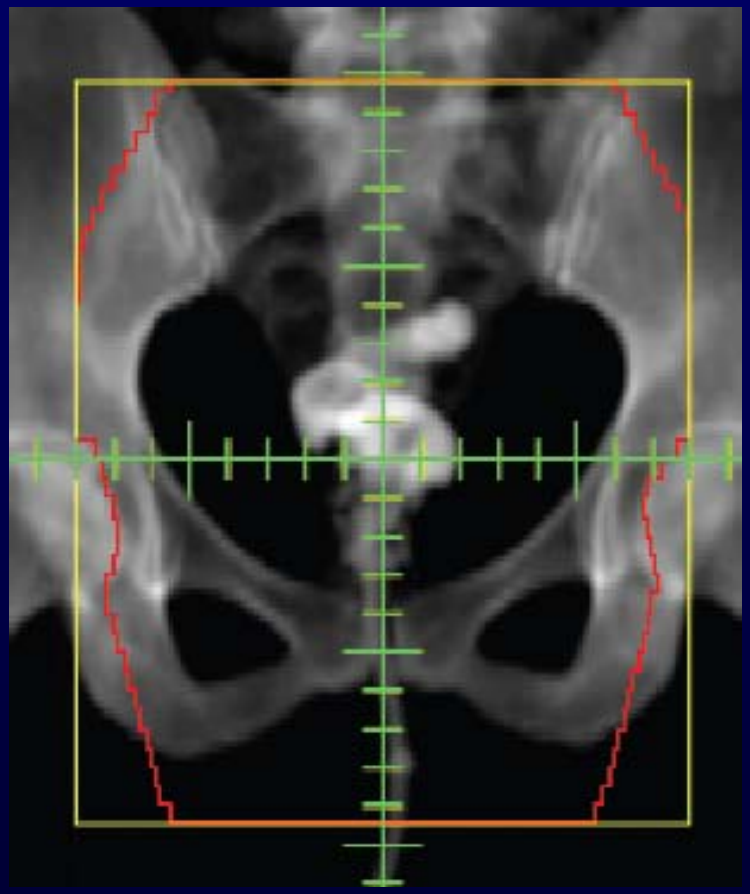


Portal image

Portal Field Verification



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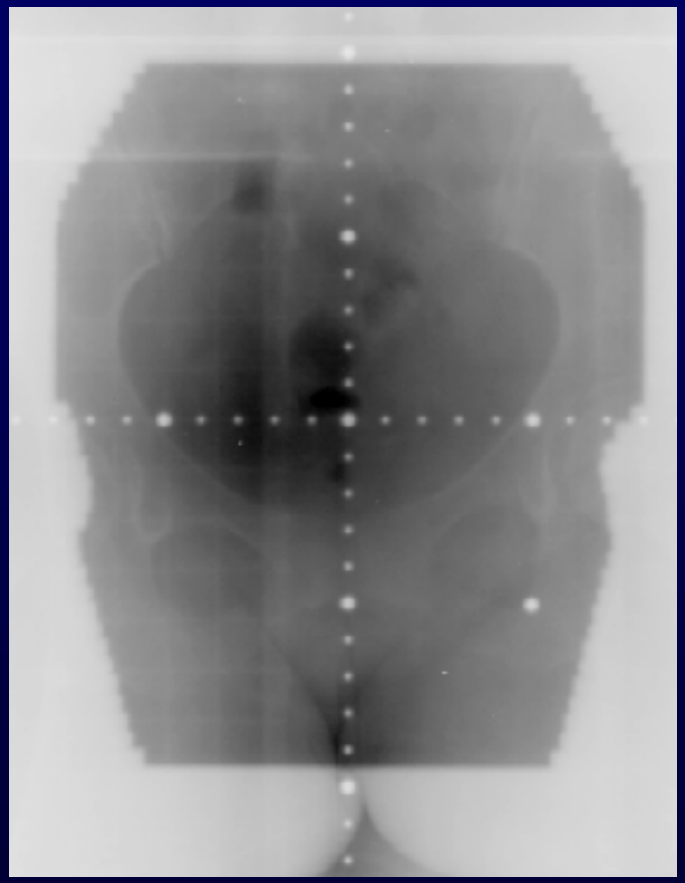
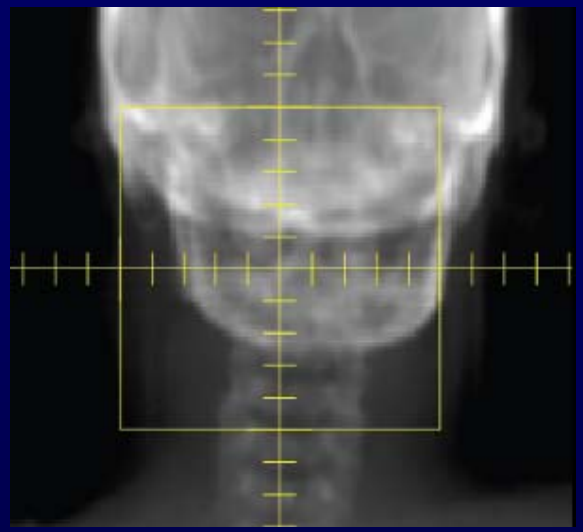
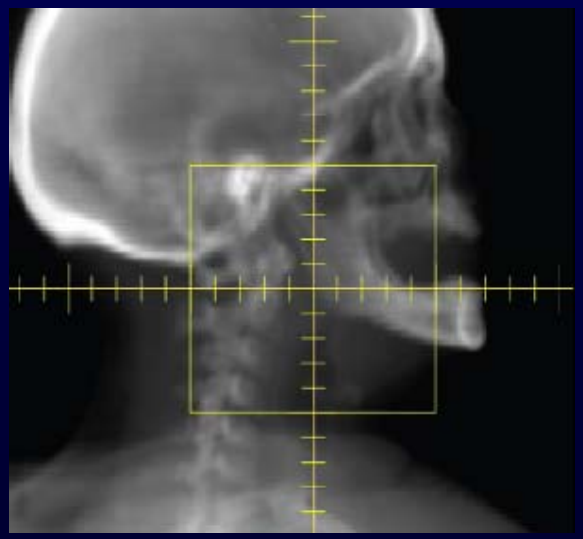


Portal image

Isocenter Verification (MV/MV)





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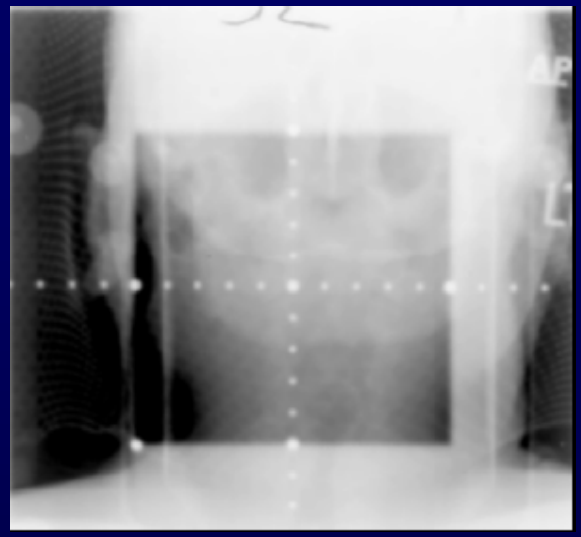
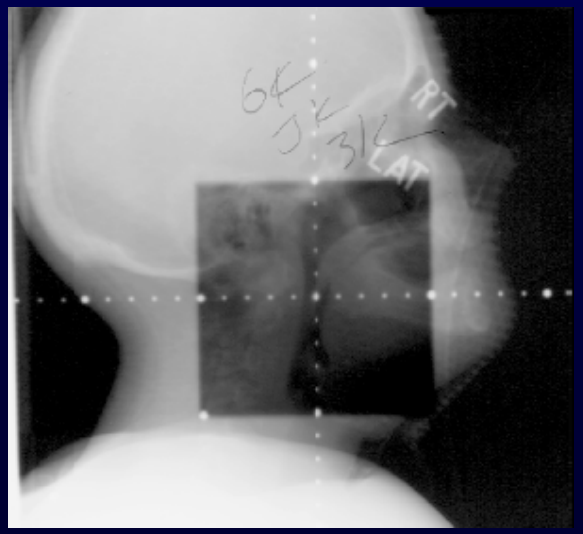
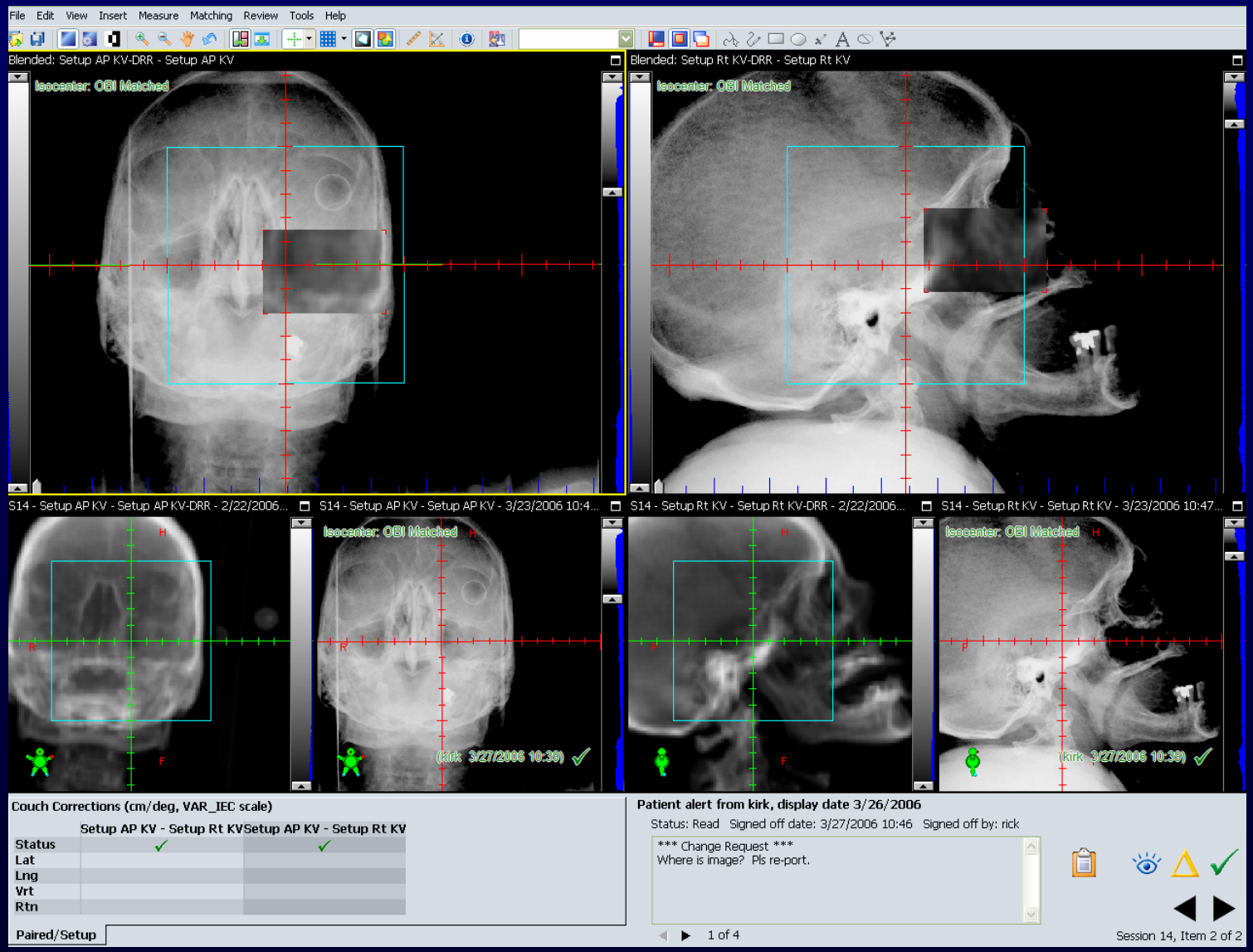


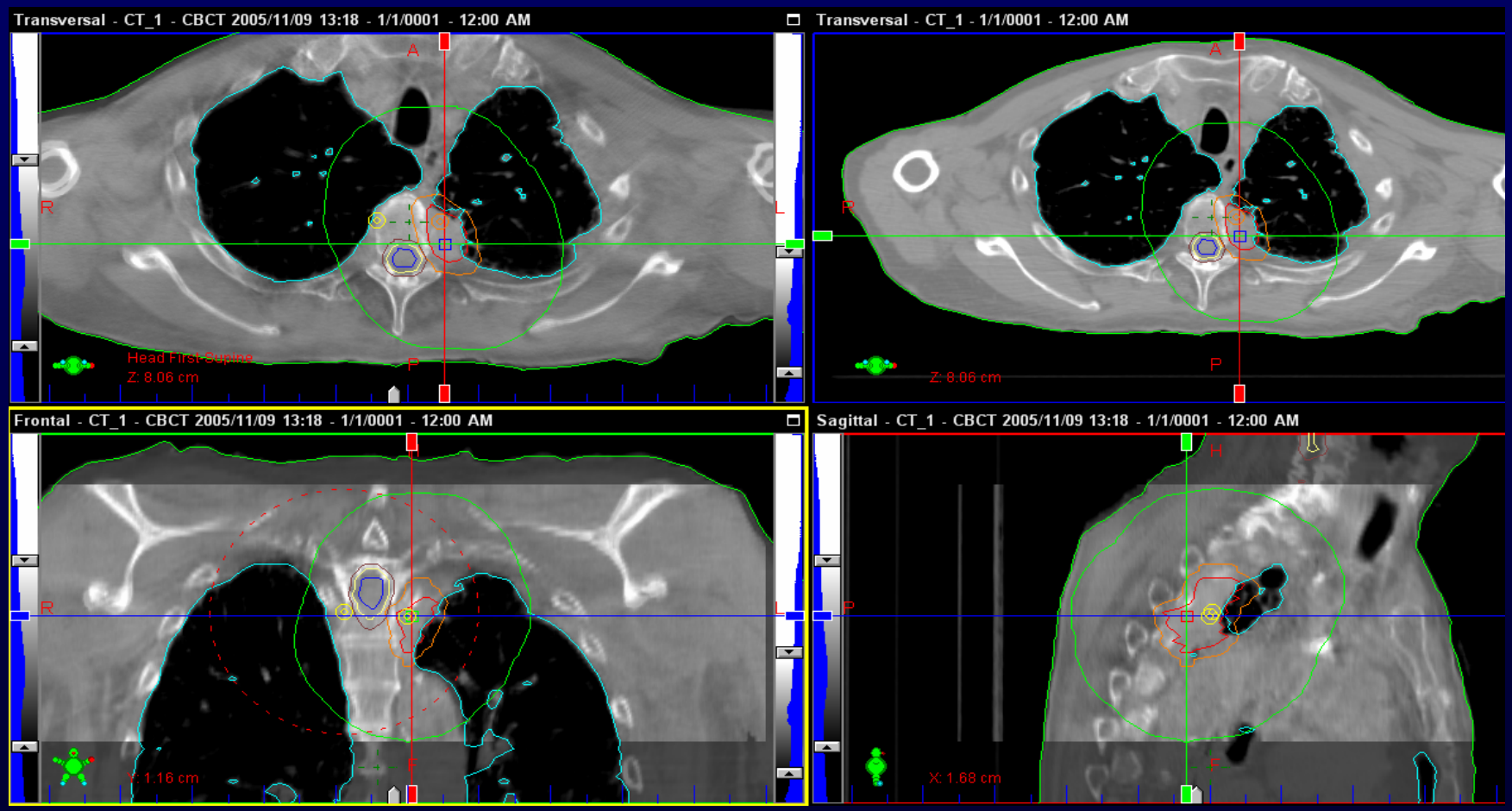


Portal image

Isocenter Verification (kV/kV)

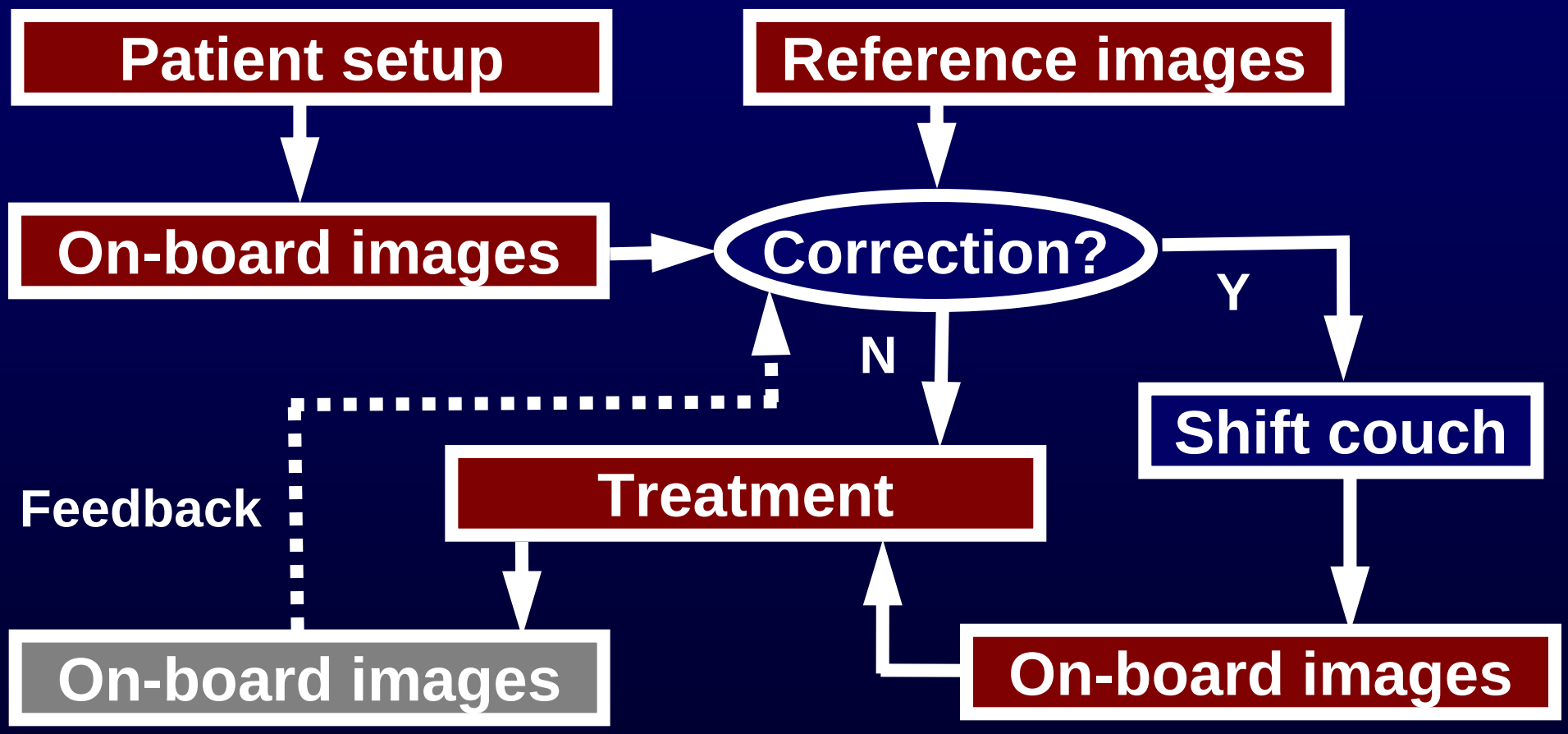


On-Board CBCT for Soft Tissue

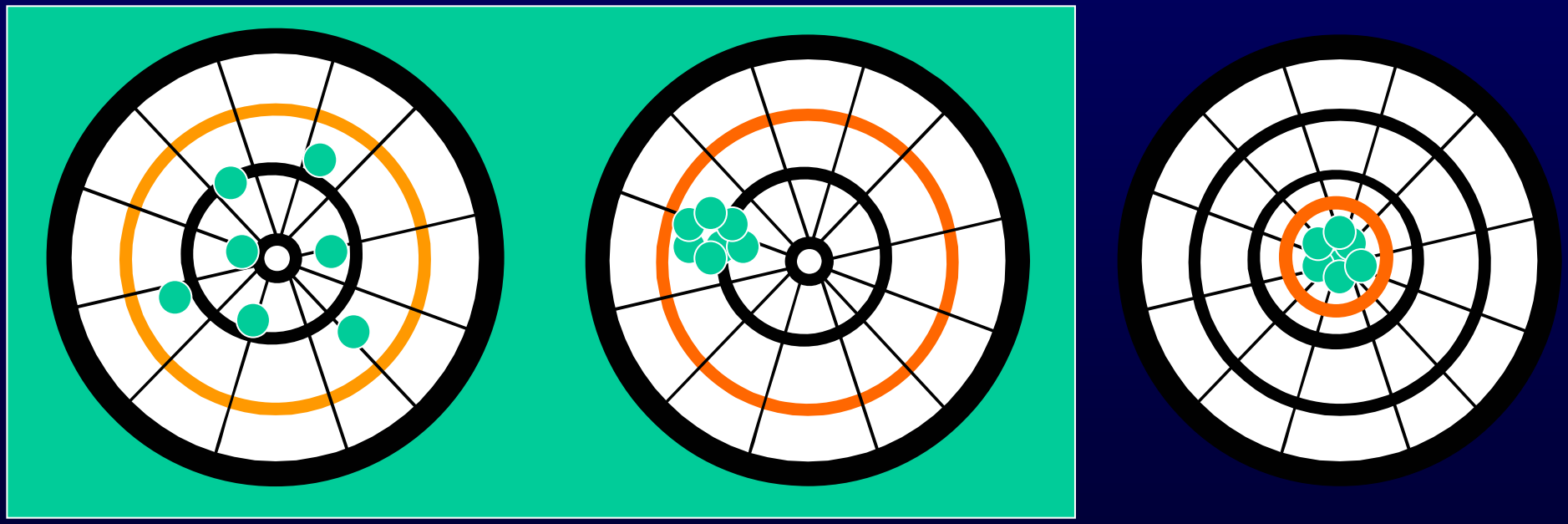


Reference image **Portal image**

On-Line Portal Verification



What Will On-Line Verification Do for Precision and Accuracy?

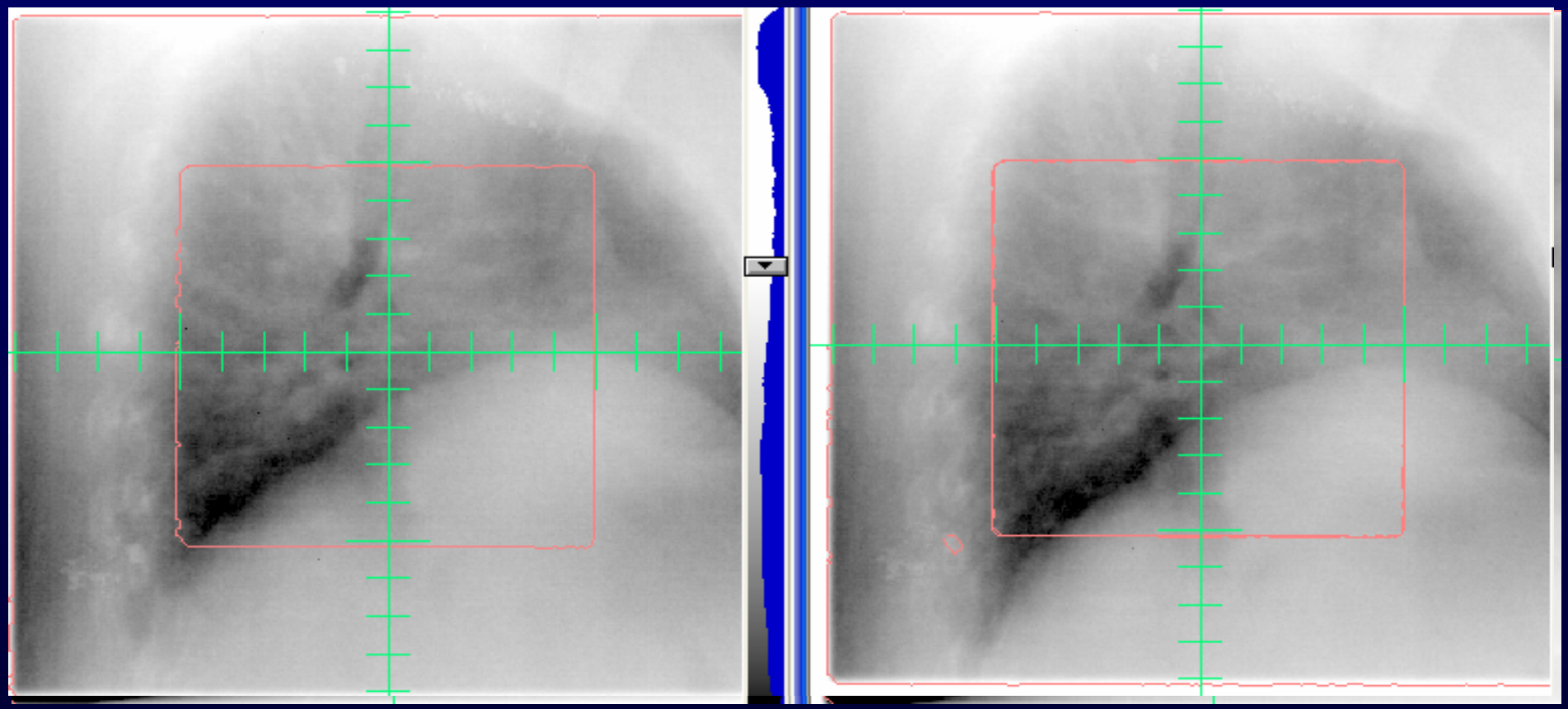


Random error

Systematic error

Systematic & Random error

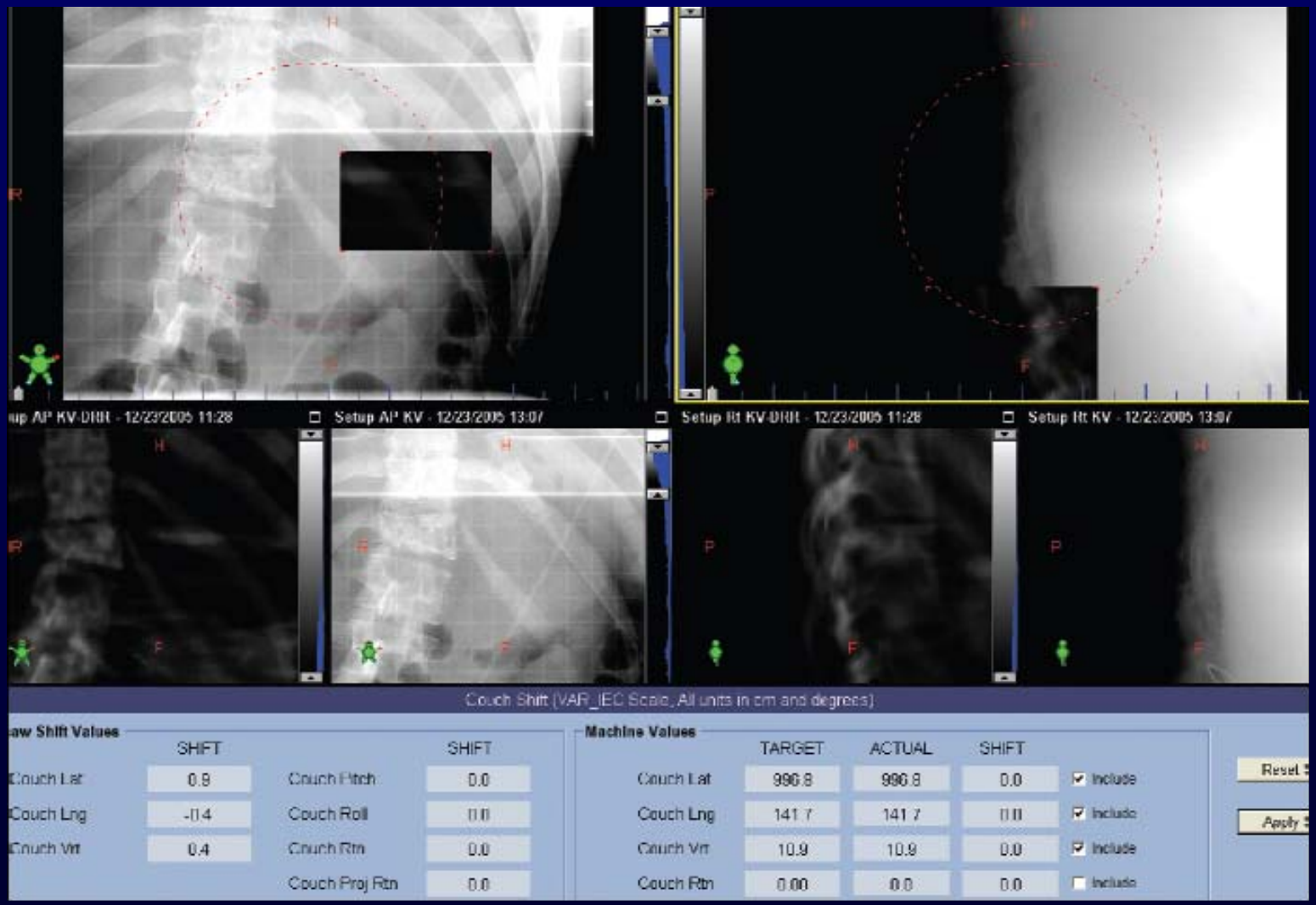
On-Line Localization – MV/MV



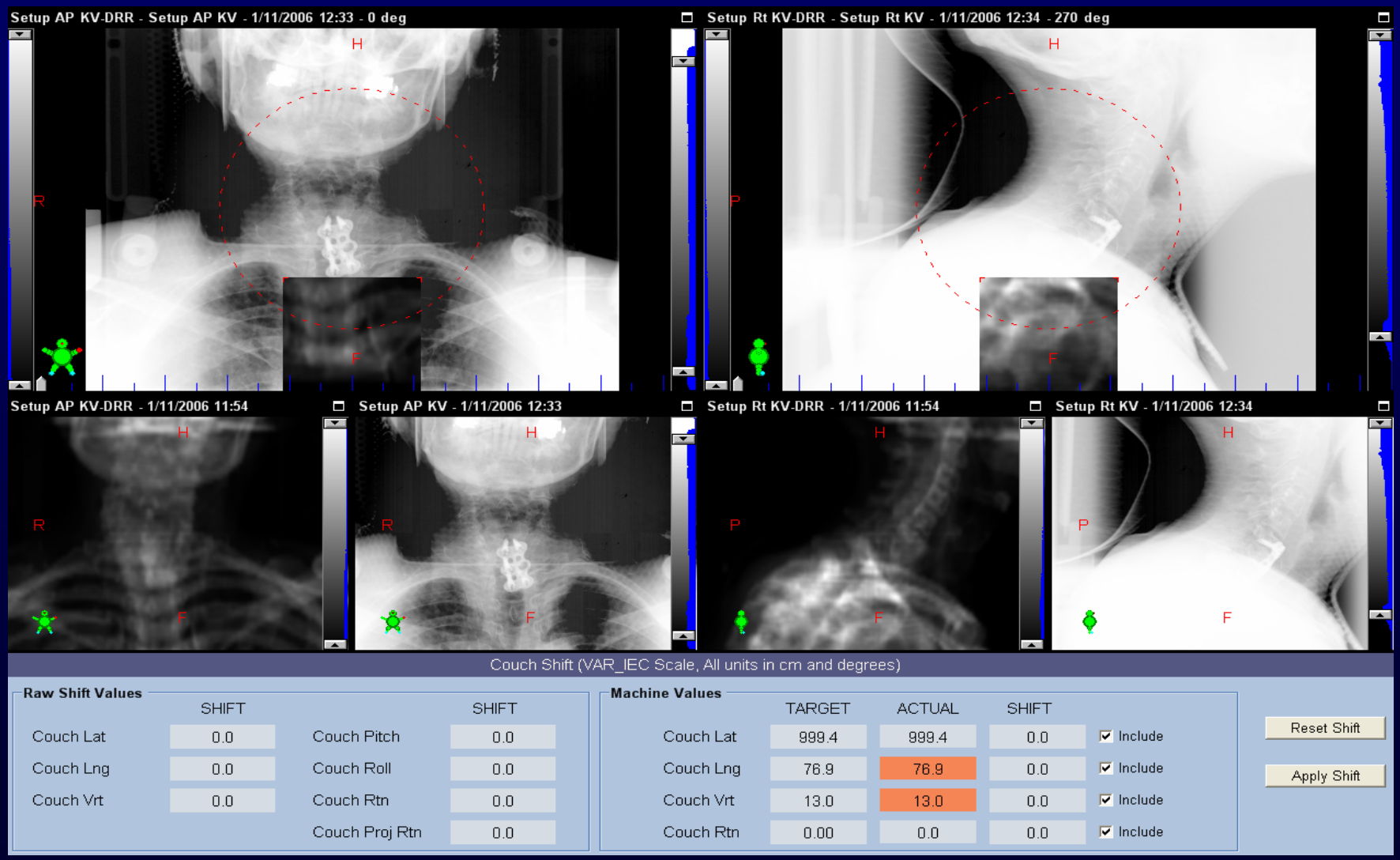
Before beam-on

After treatment

On-Line Localization kV/kV



On-Line Localization - kV/MV



Planning CT and On-Board CBCT

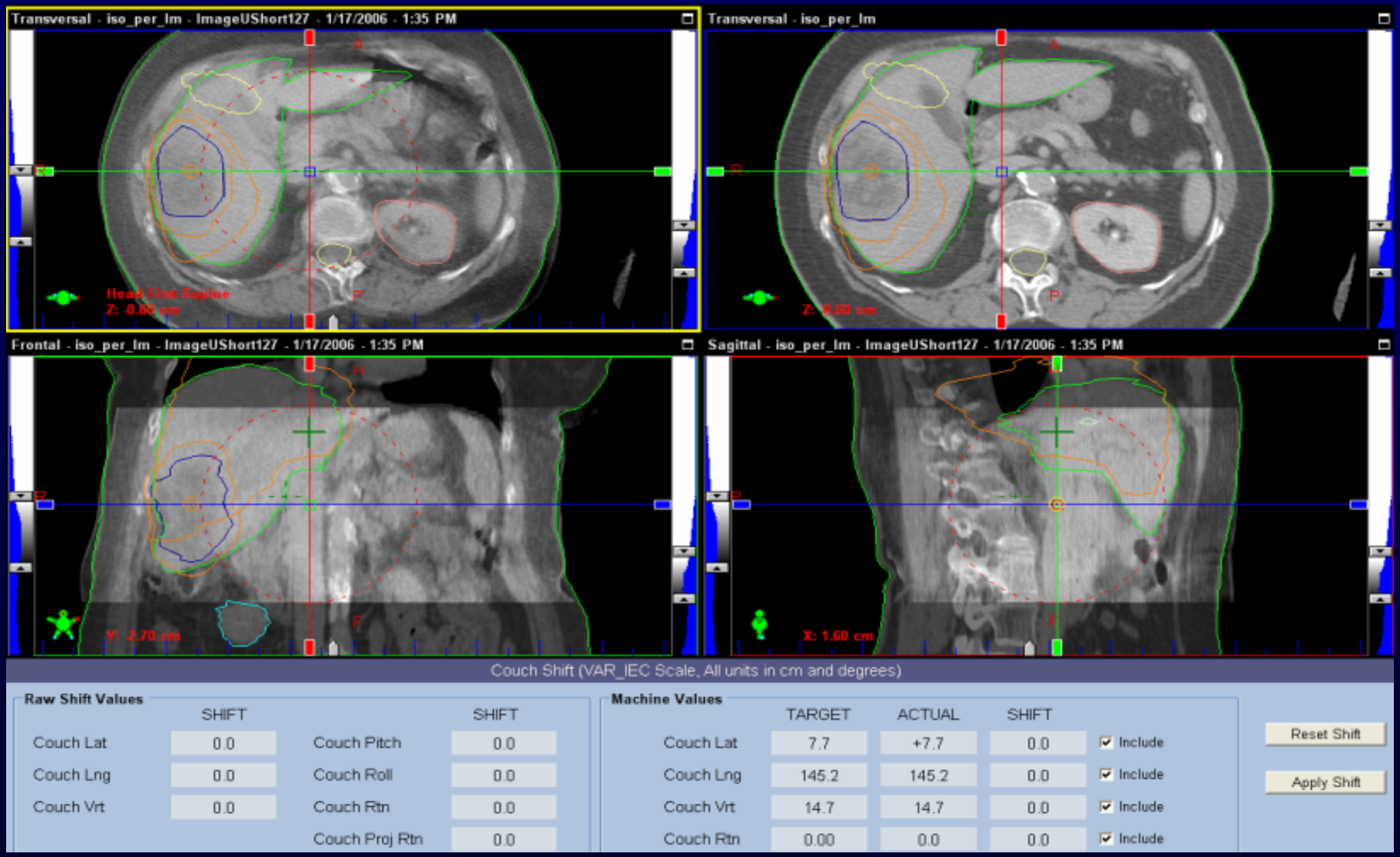


Image Fusion

- Manual
  - Skill and knowledge: always needed
- Automatic
  - Control-point fusion
  - Edge-based fusion
  - Moment-based fusion
  - Mutual information/correlation based fusion
- Rigid and non-rigid (deformable)

Image Fusion – 2D to 3D

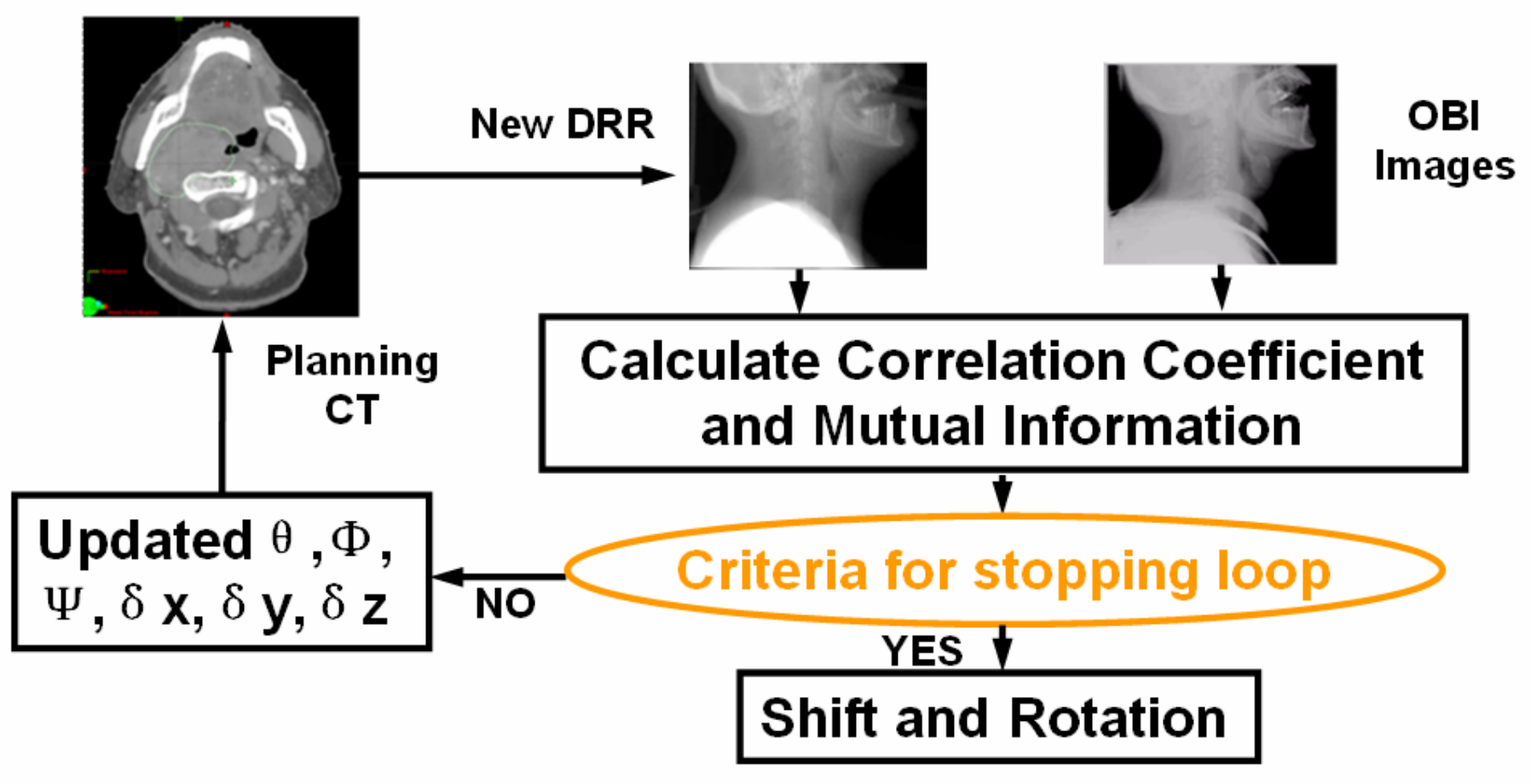


Image Fusion – 2D to 3D

- Shift and Rotation
- Rigid body 3-D to 2-D
- Iterative DRRs
- Different shift and angulations
- Mutual image information

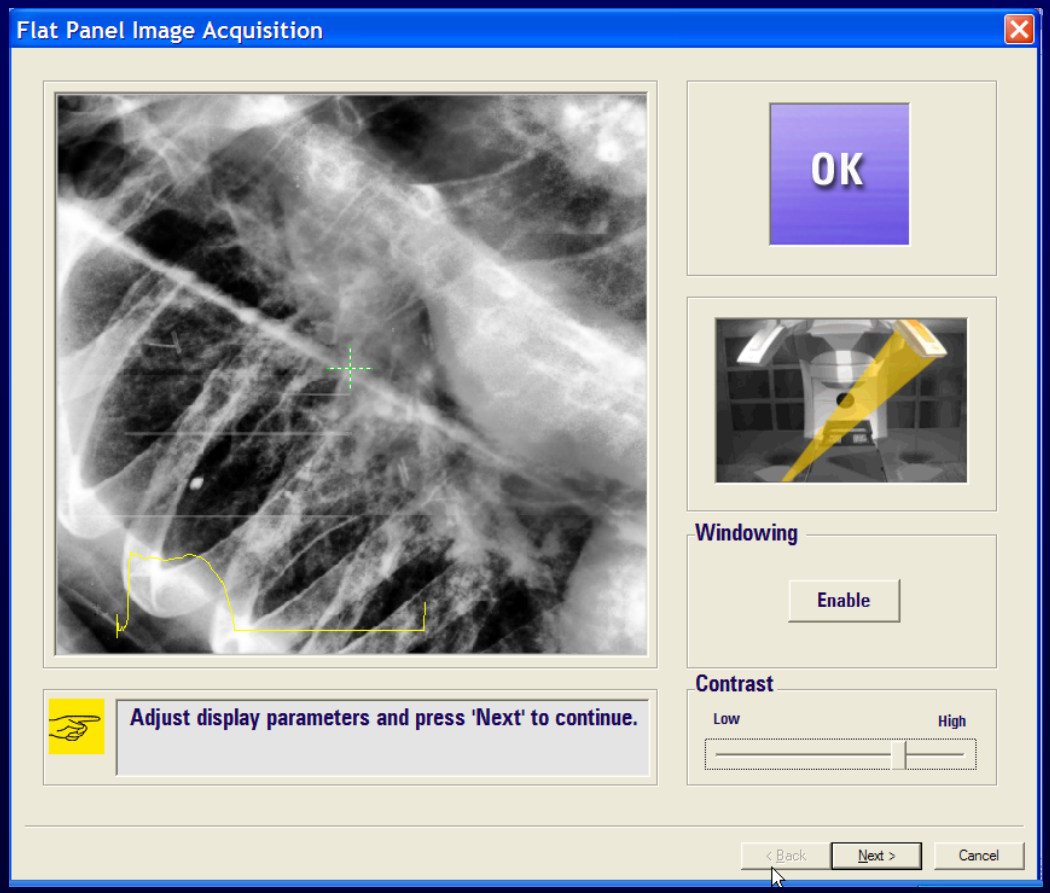


Image Fusion – 3D to 3D

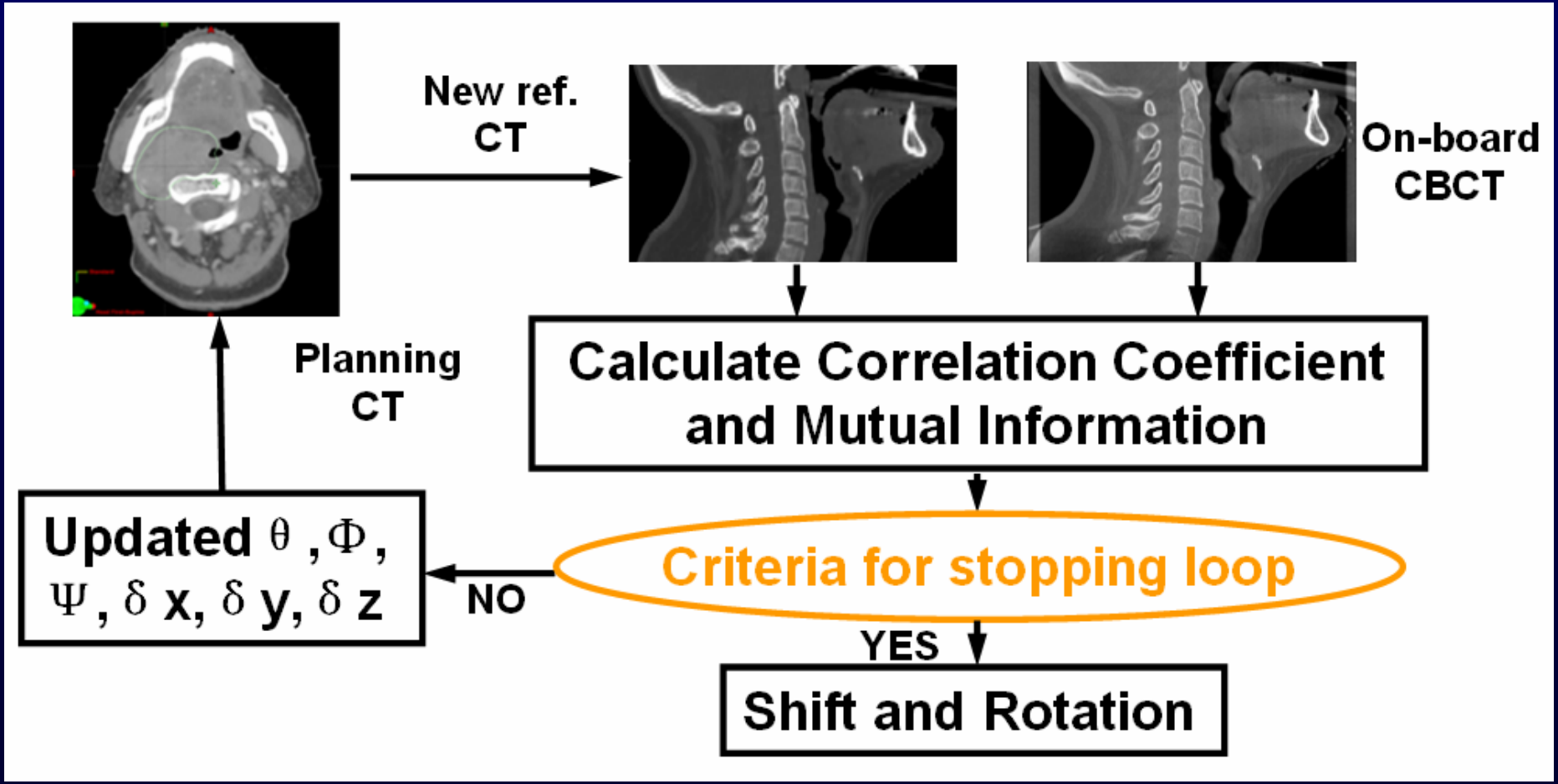
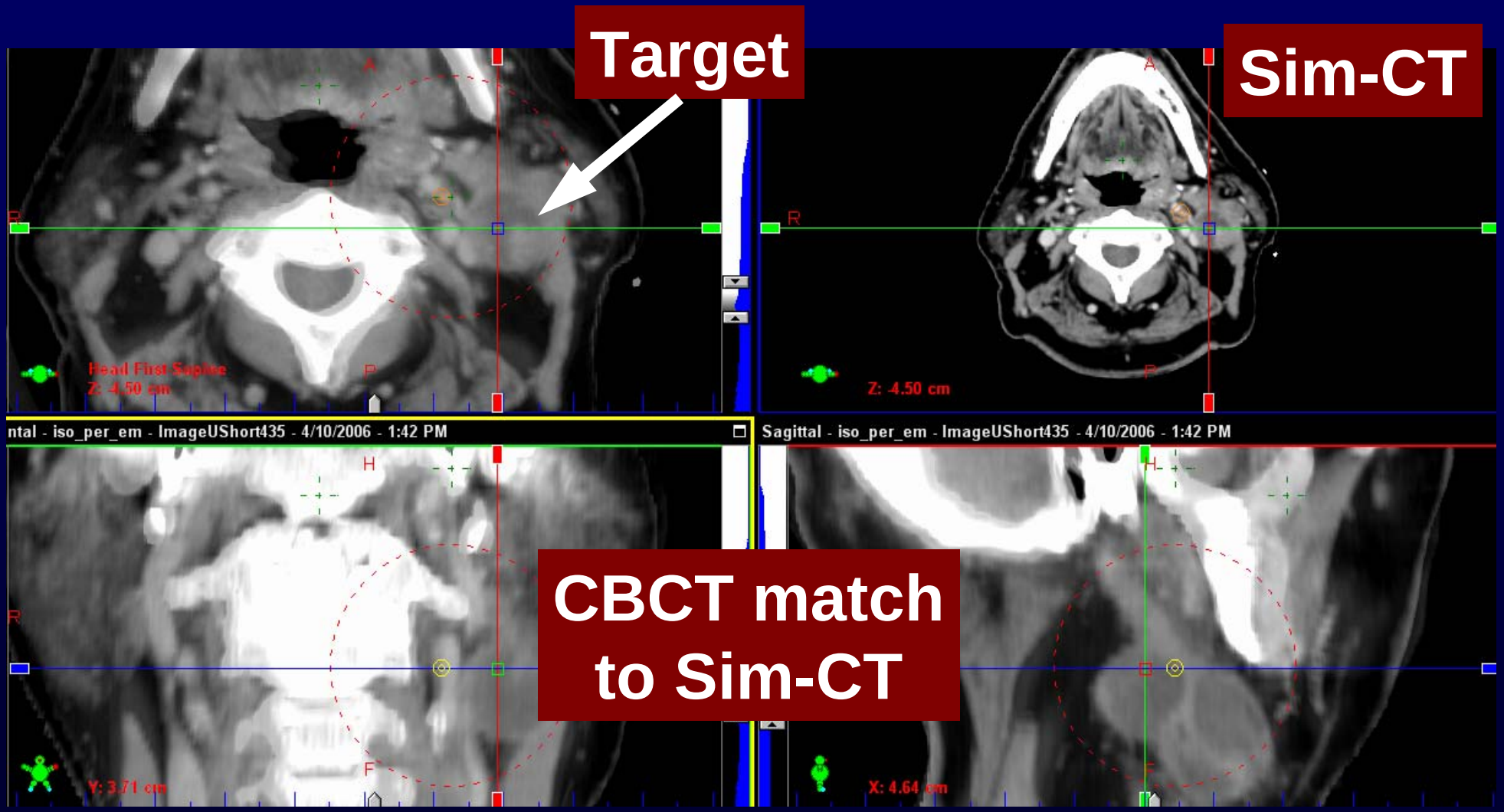


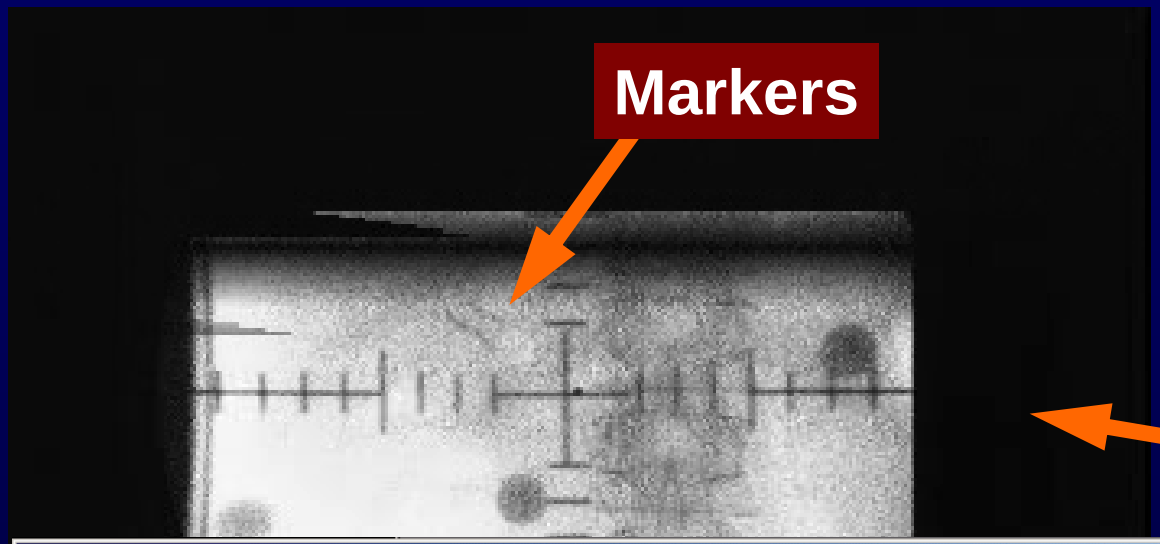
Image Fusion – 3D to 3D

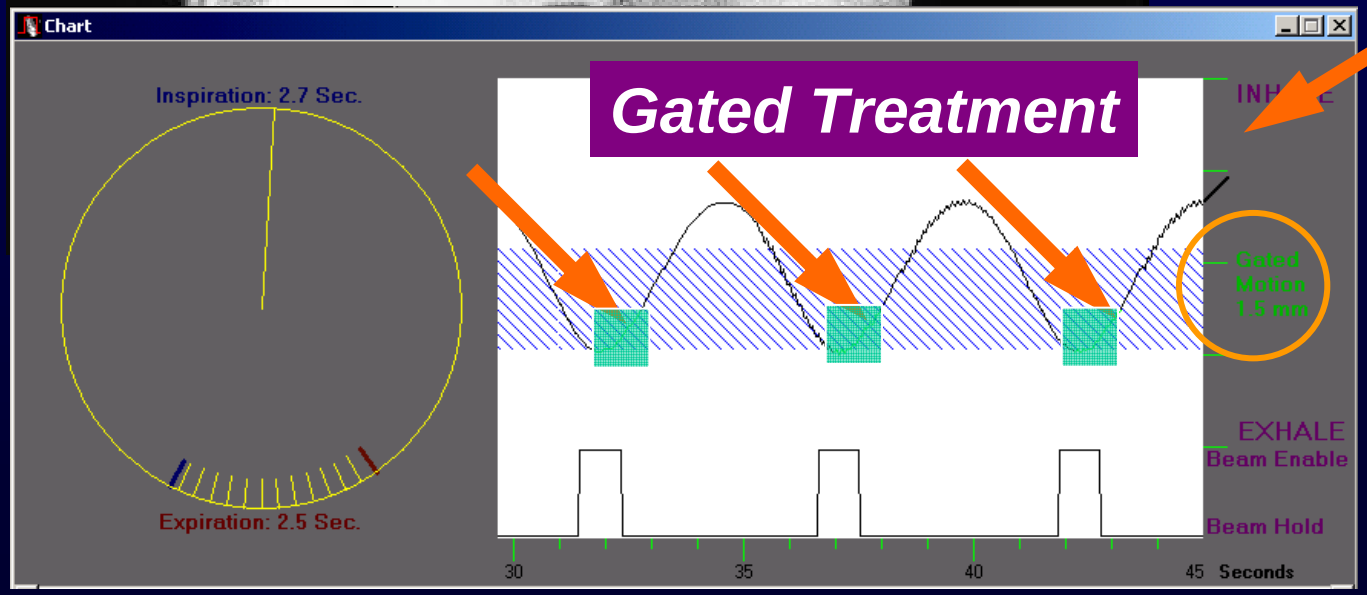


Imaging for Respiratory-Gated Treatment

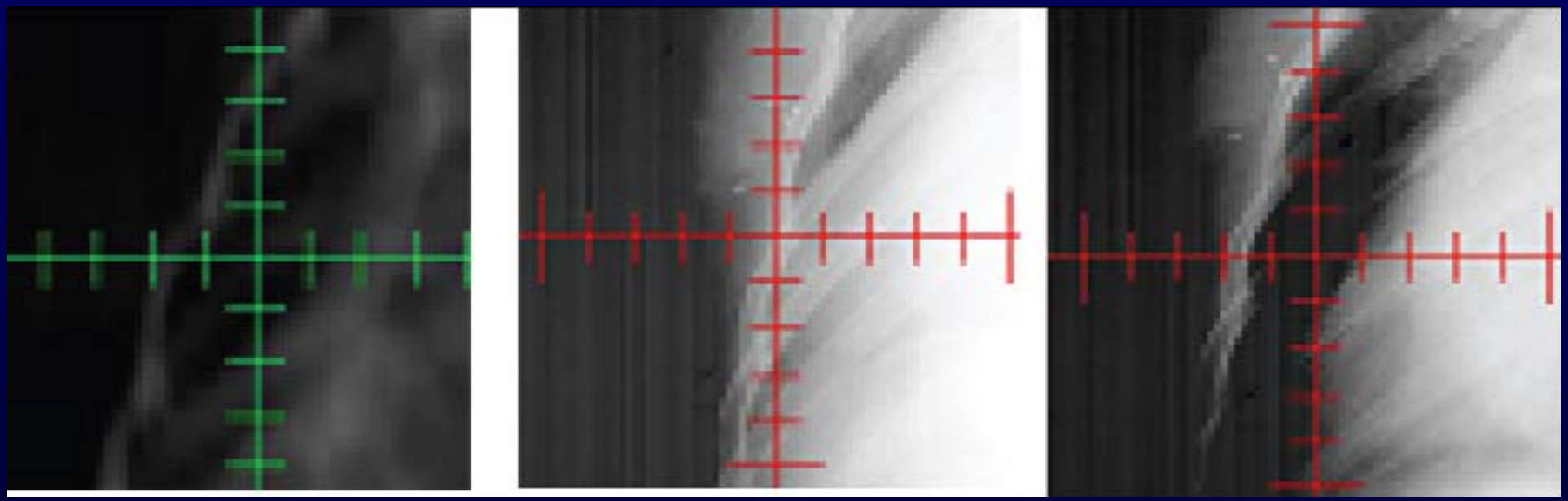
- Anatomical imaging
  - Breath-hold
  - Gated treatment
  - Real-time portal verification
- Dosimetric imaging
  - Intensity map

4-D Fluoroscopic Imaging



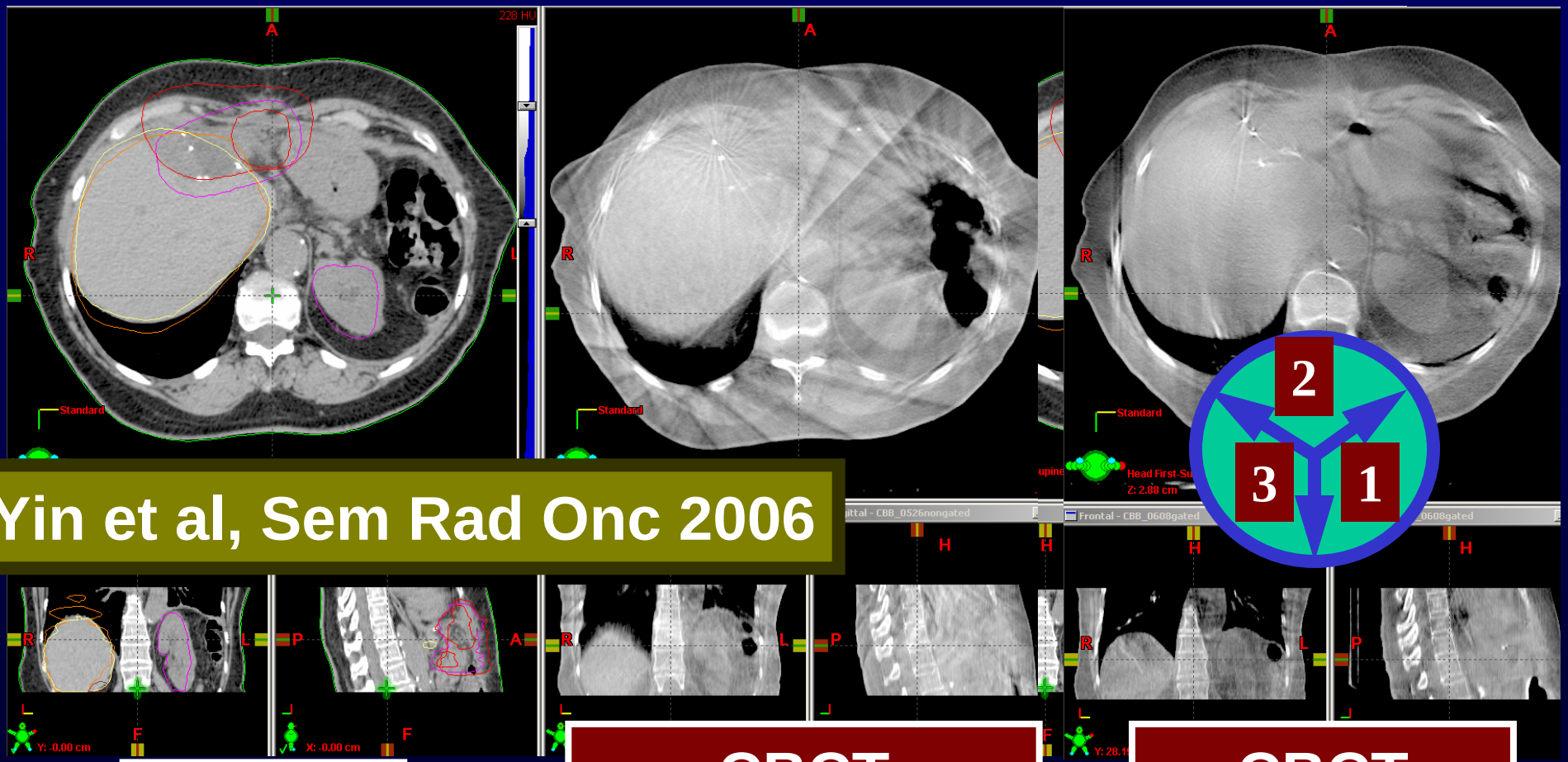


Breath-Hold Treatment Localization



DRR (breath-hold) kV (free-breathing) kV (breath-hold)

Breath-Hold CBCT and Treatment



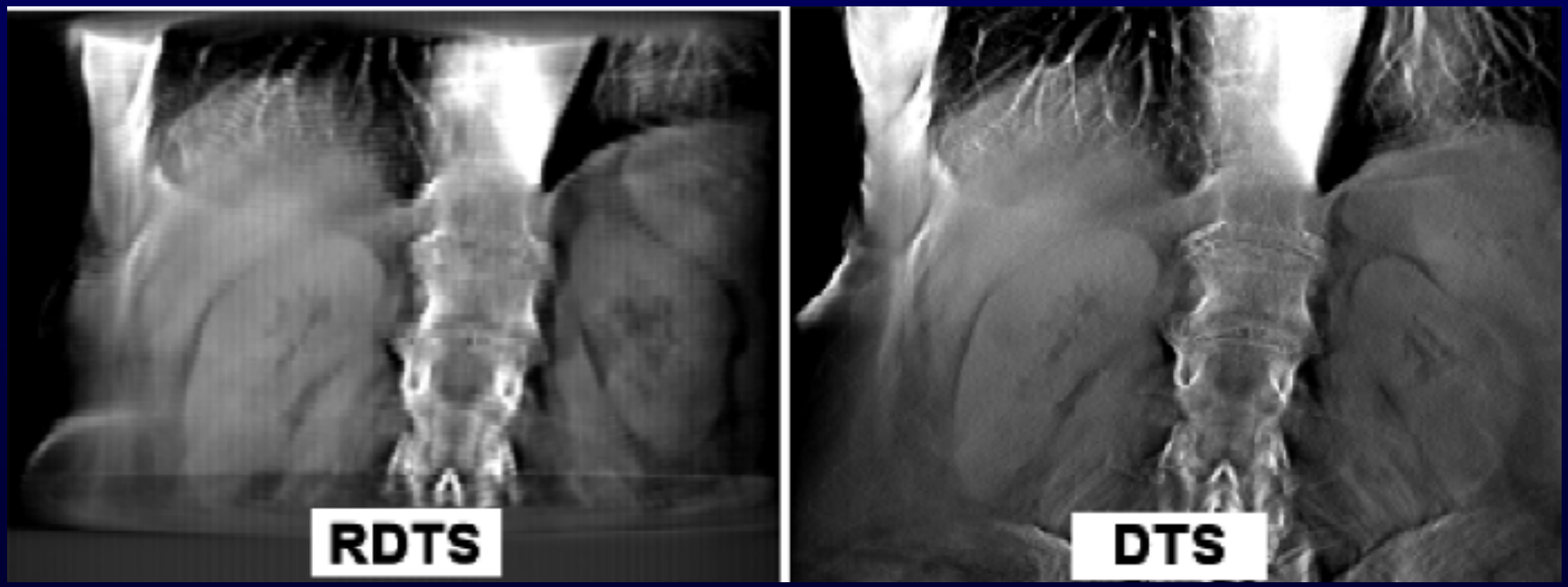
Yin et al, Sem Rad Onc 2006

Sim CT

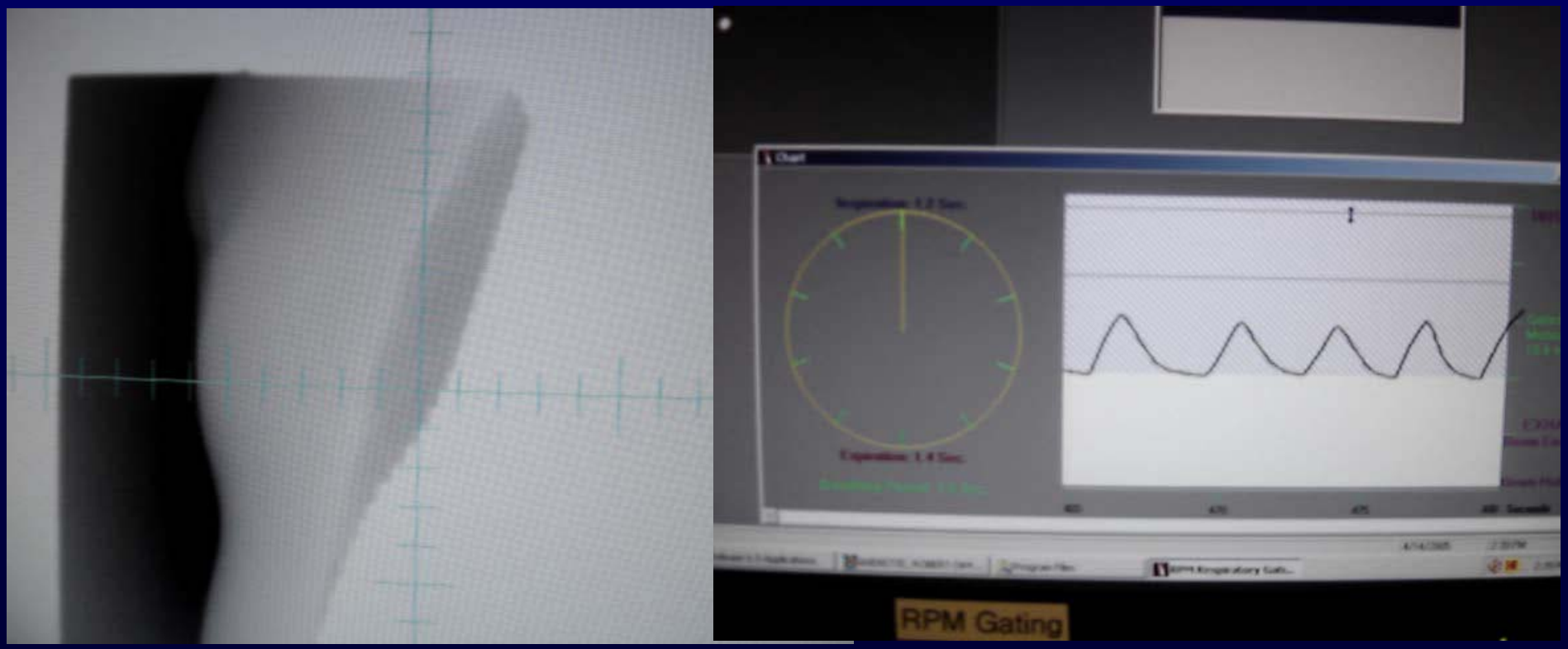
CBCT
Free-breathing

CBCT
Breath hold

Breath-Hold Digital Tomosynthesis

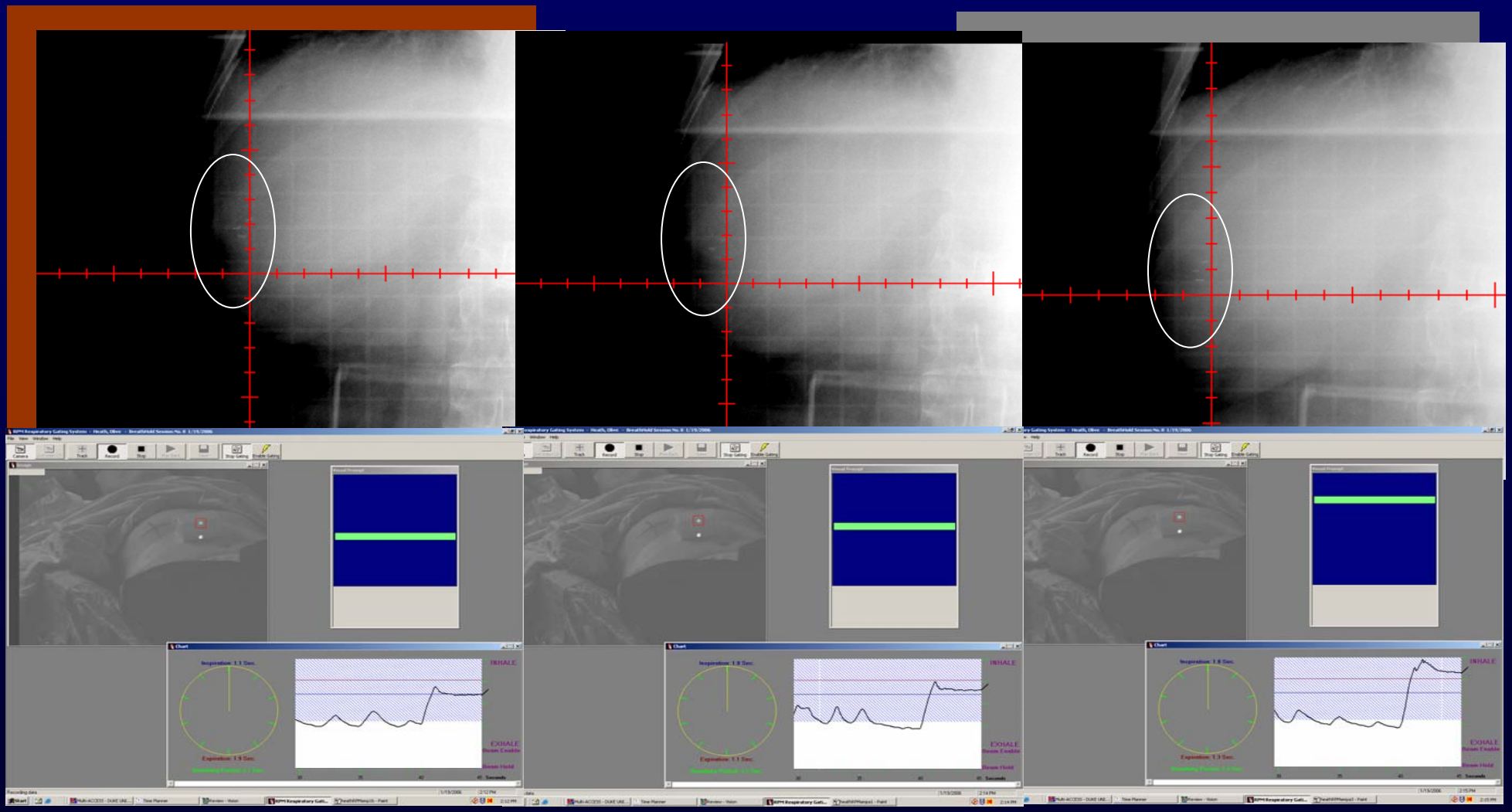


Breath Real-Time Portal Verification

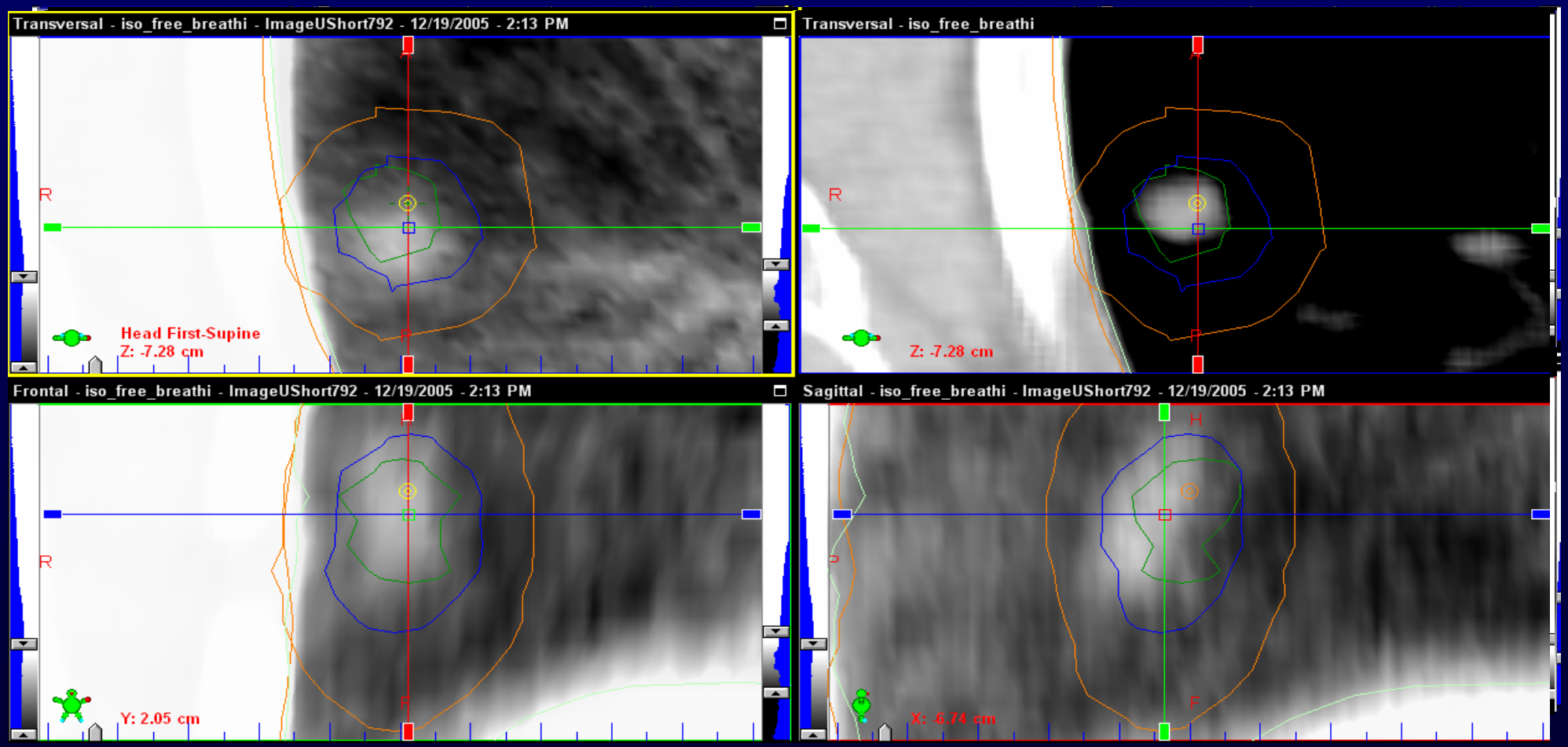


20 portal images in cine mode with < 1 s interval

Liver - Effect of Breath-Hold



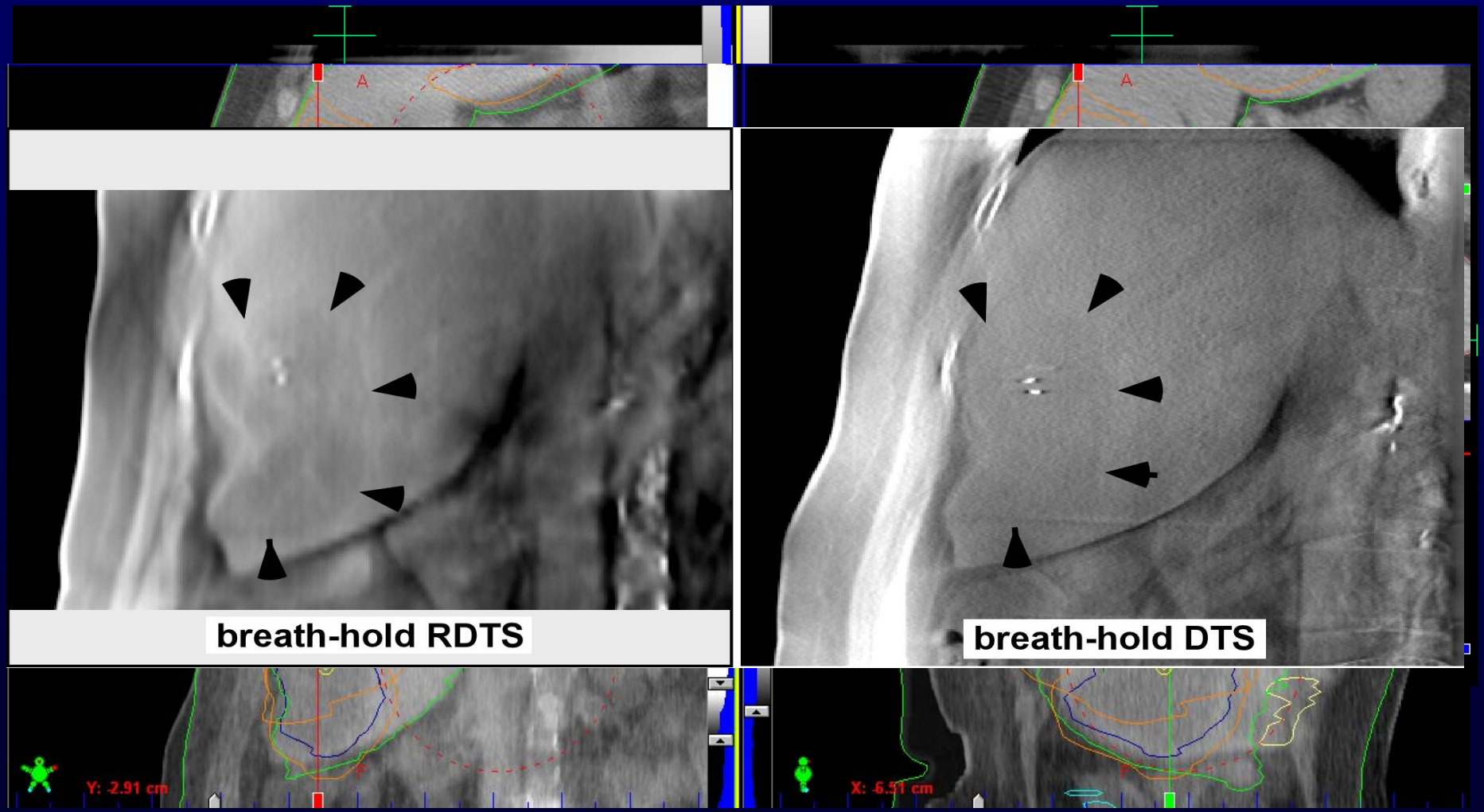
Free-Breath ITV Verification with CBCT



Planning CBCT in free breathing position

Patient shift after correction

On-Board Breath-Hold for Liver



Special Considerations

- Treatment Time with Corrective Action
- Quality Assurance
- Imaging Dose
- Other Considerations

Dose/Exposure vs Imaging Modality

Modality	Dose/Exposure
Orthogonal set of MV digital images (Kutcher et al. 1994)	5–8 cGy
Orthogonal set of KV images	<0.1 cGy
CBCT Body scan (Fritsch et al. 1995; Yoshizumi et al. 2006)	3–4 cGy
CBCT Head scan (Yoshizumi et al. 2006)	8 cGy
MVCT of Tomotherapy (Sheng et al. 2005)	1 cGy
CT simulation scan (Judy et al. 1977)	3–4 rads

QA for OBI/CBCT

- **Safety and functionality**
  - Door interlock, collision interlock, beam-on sound, beam-on lights, Hand pendant control, and network-flow.
  - All test items are verified during tube warm-up (< 5 min)
- **Geometric accuracy**
  - OBI isocenter accuracy
  - Accuracy of performance for 2D2D match and couch shift
  - Mechanical accuracy (arm positioning of KVS and KVD)
  - Isocenter accuracy over gantry rotation
- **Image quality**
  - OBI (radiography): contrast resolution and spatial resolution
  - CBCT (tomography): HU reproducibility, contrast resolution, spatial resolution, HU uniformity, spatial linearity, and slice thickness.

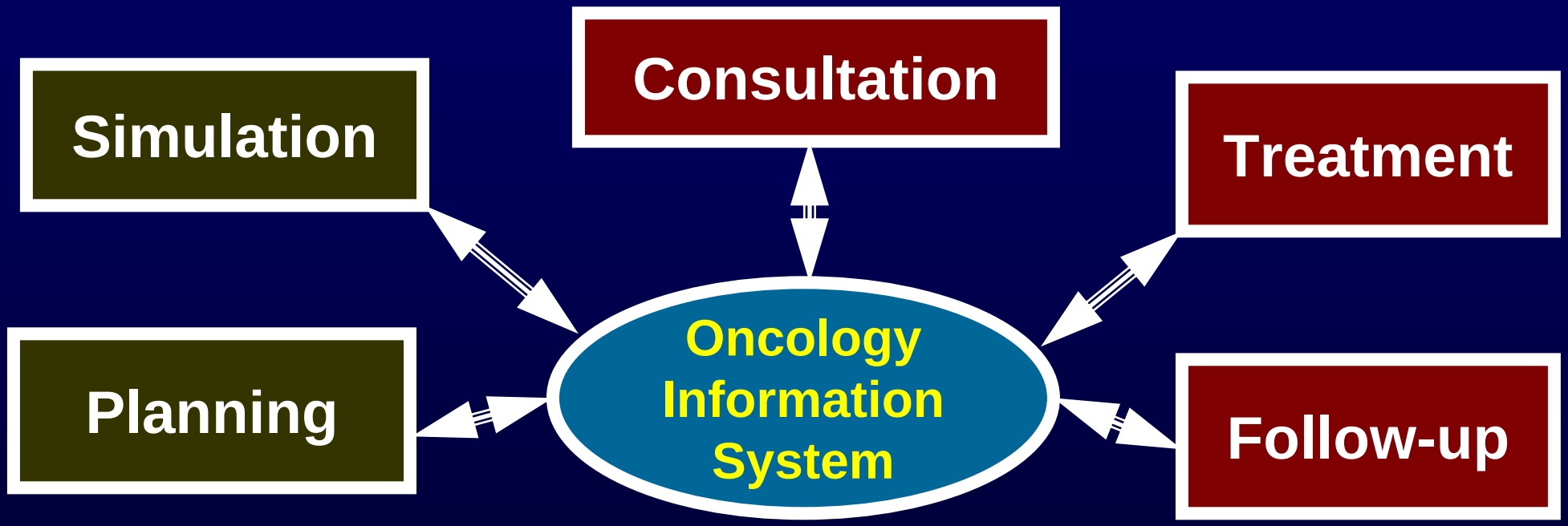
Total Treatment Time for IGRT

Patient setup in the room	2 – 5 min
OBI kV/kV or MV/kV imaging	~ 1 min
2D2D matching analysis	2 – 5 min
CBCT imaging	3 min
3D3D matching analysis	2 – 5 min
Re-positioning	~ 1 min
Treatment delivery	10 – 15 min
Total treatment time for IGRT with CBCT	20 – 35 min
Total treatment time for IGRT without CBCT	15 – 25 min

Other Considerations

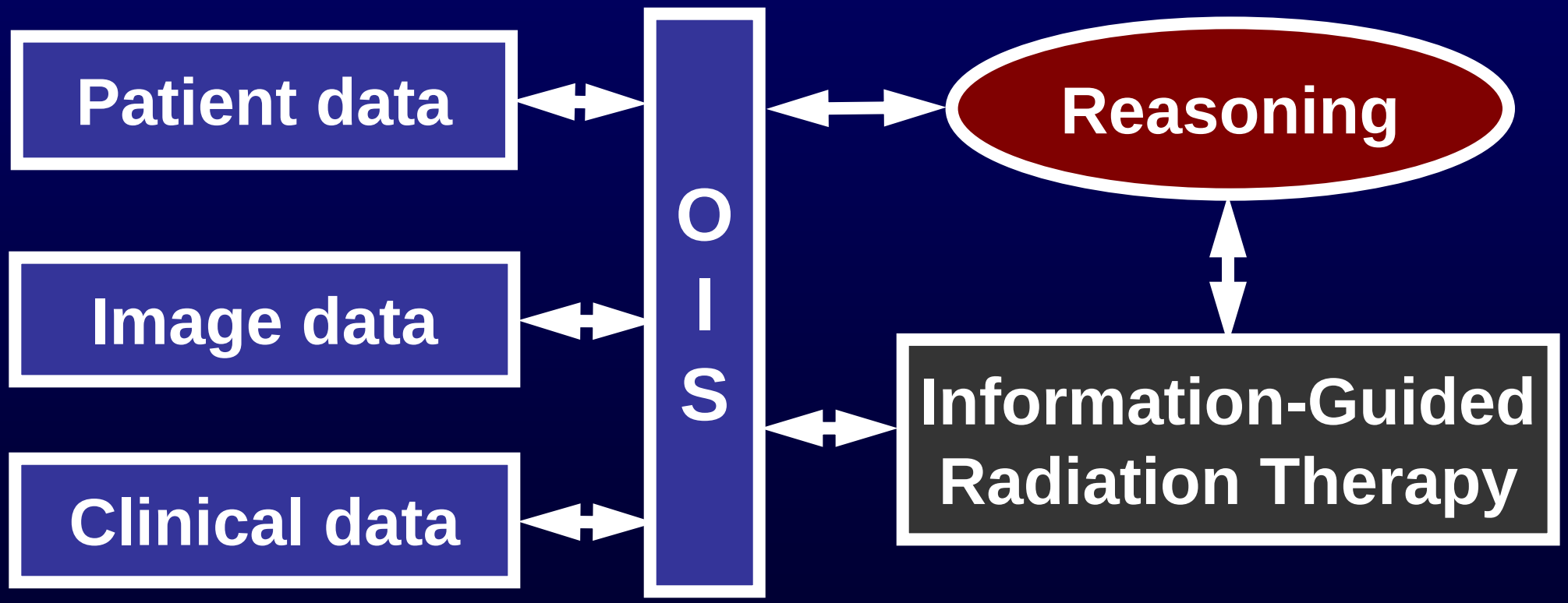
- Hardware
- Software
- Network
- Power
- Financial
- Training
- Staffing
- Billing

Information Management: Departmental Integration

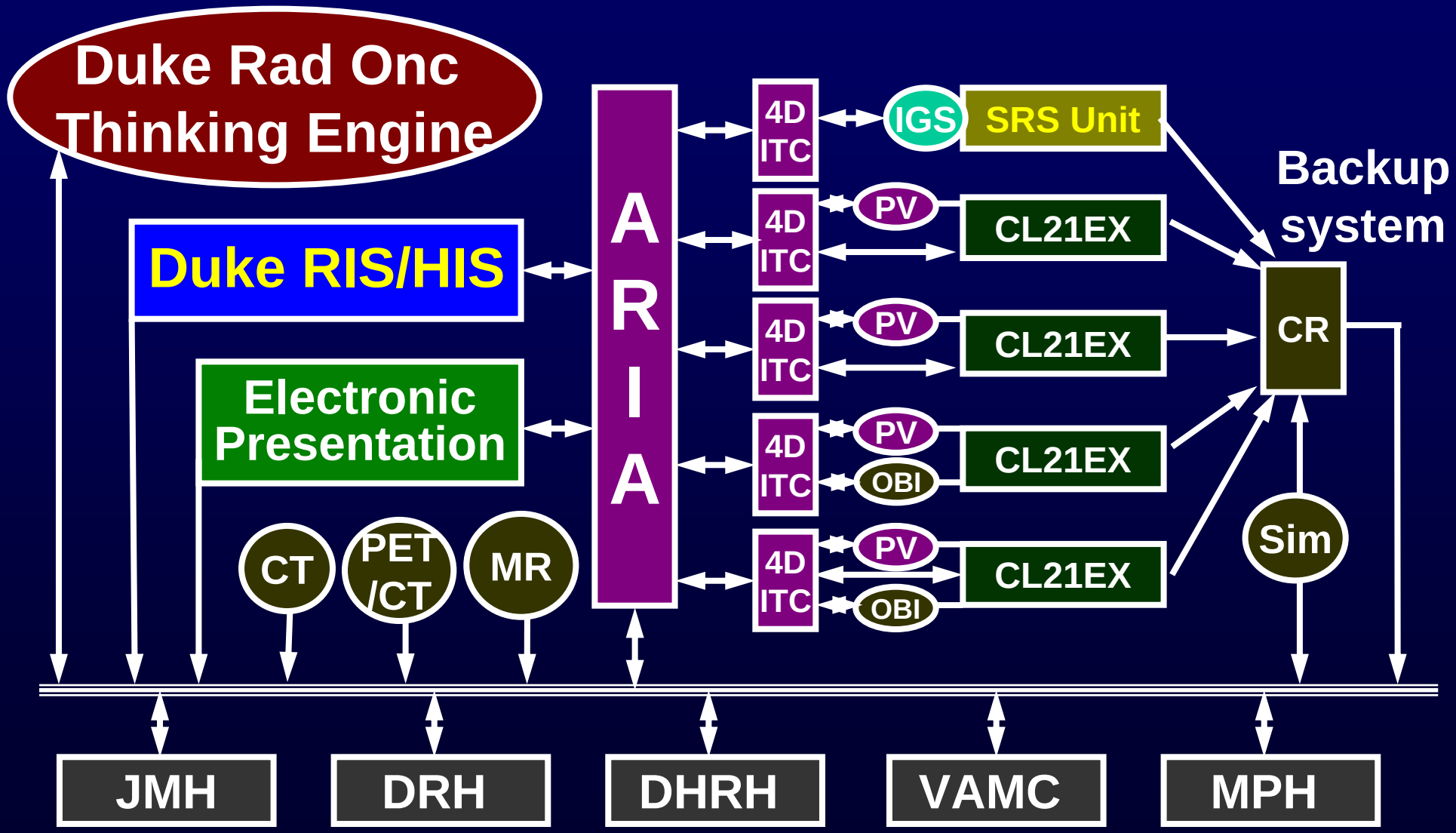


- Computation (Seconds, minutes?)
- Speed (Seconds?)
- Accessibility (Anywhere?)
- Quality assurance (Pre-, on-line? after?)

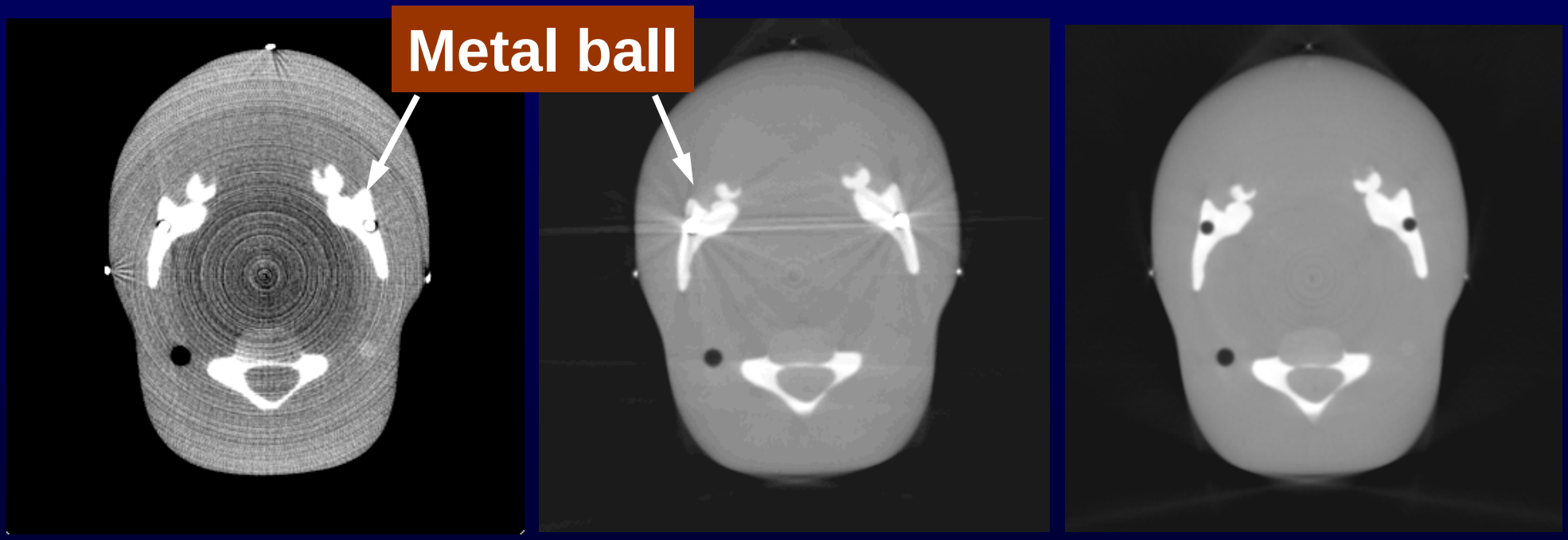
What Does IGRT Really Mean?



Planned Duke IGRT-2006



On-Board kV and MV CBCT: Effect of Metal Artifact and Blurring

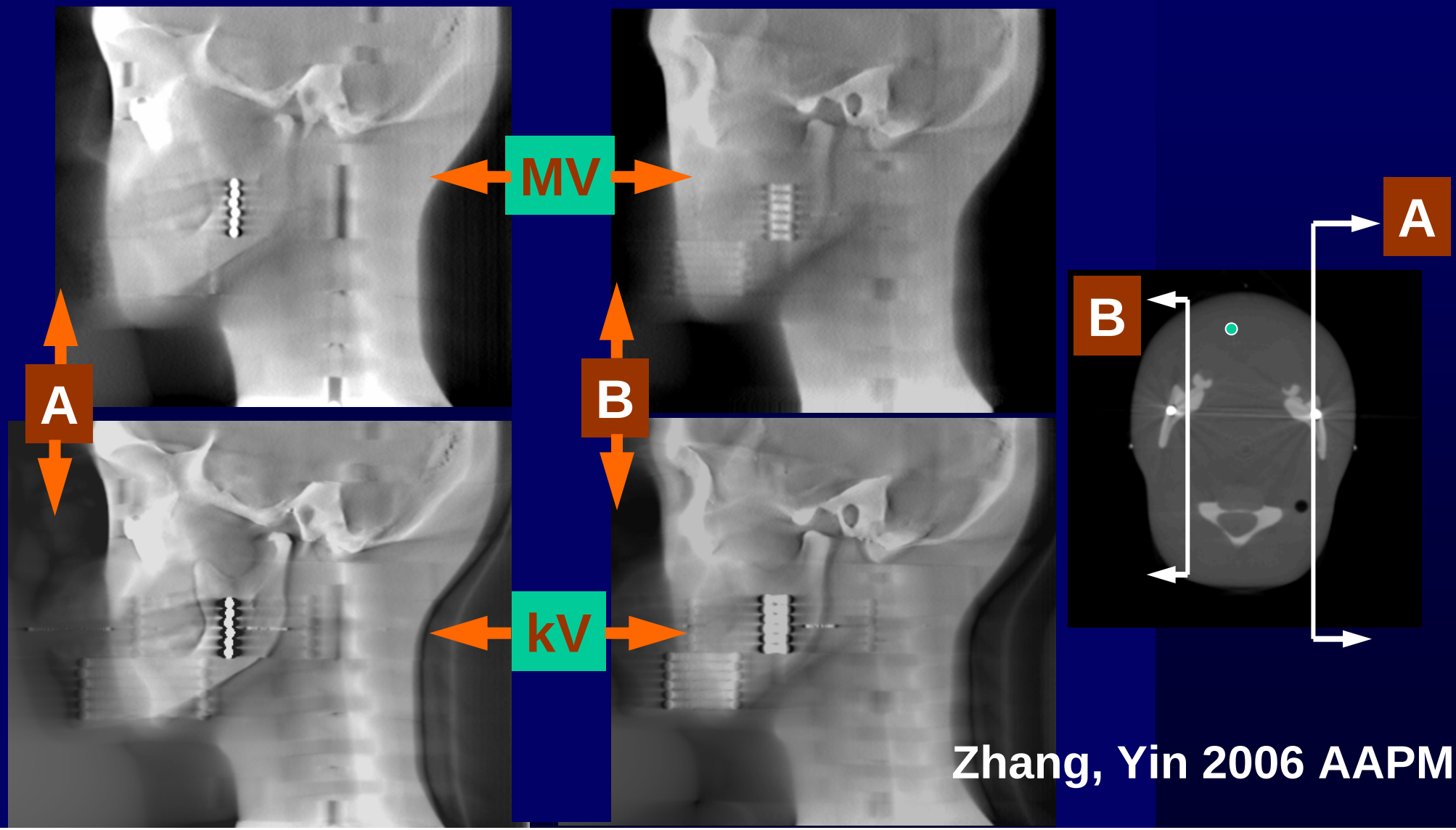


MV CBCT
with metal ball

kV CBCT
with metal ball

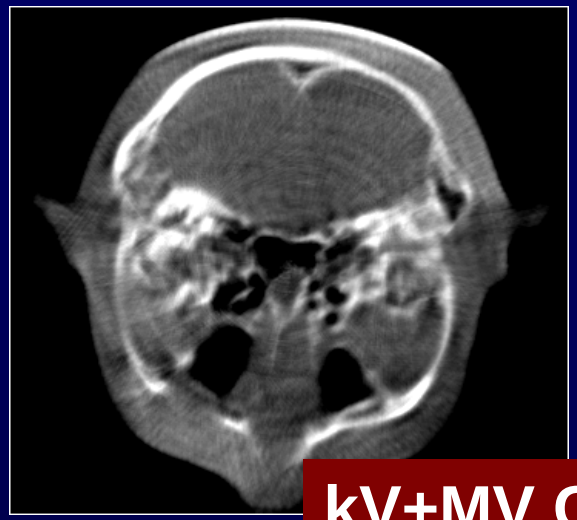
kV CBCT no
metal ball

On-Board kV and MV DTS: Effect of Metal Artifact and Blurring



Zhang, Yin 2006 AAPM

kV/MV Dual Beam CBCT Images



kV+MV CBCT

Diag CT

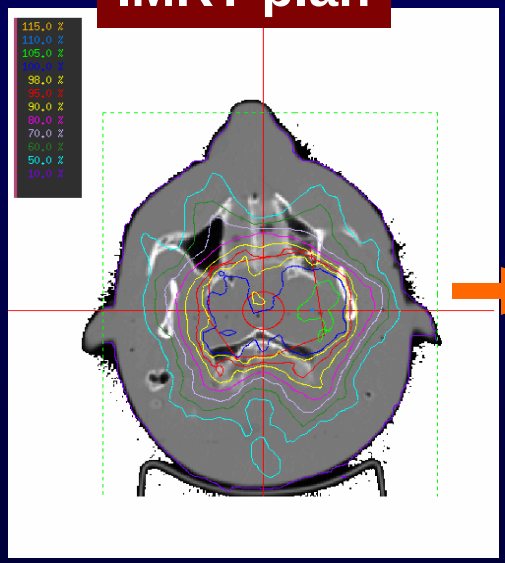
MV-CBCT

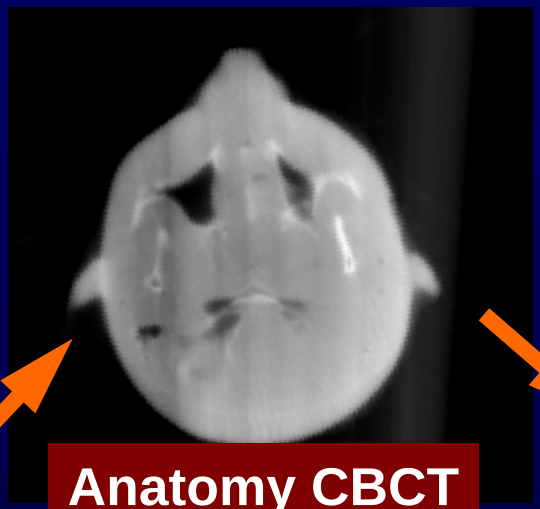
kV-CBCT

Yin et al.
Med Phys 2005

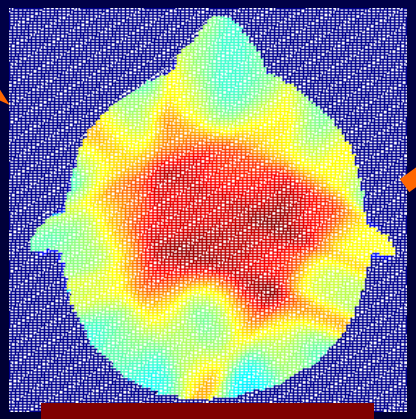
3-D Dose and Anatomy Verification

IMRT plan

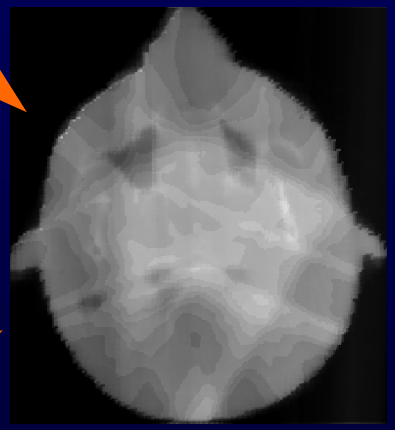




Anatomy CBCT



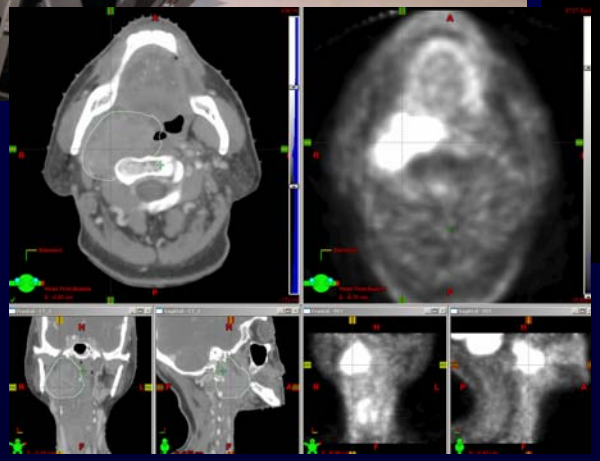
Dose CBCT



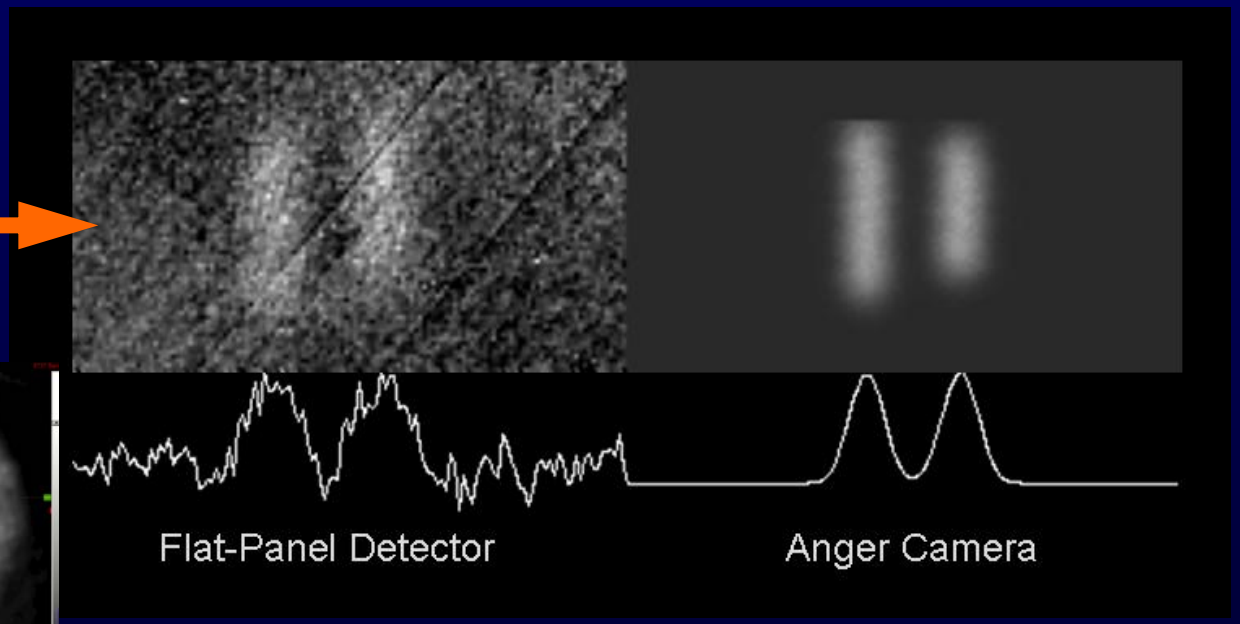
3D dose image overlaid on 3D anatomy image

Yin et al, Med. Phys. 27:1406 (AAPM 2000)

On-Board CBCT/SPECT Imaging



0.35 mCi Tc-99m line-sources



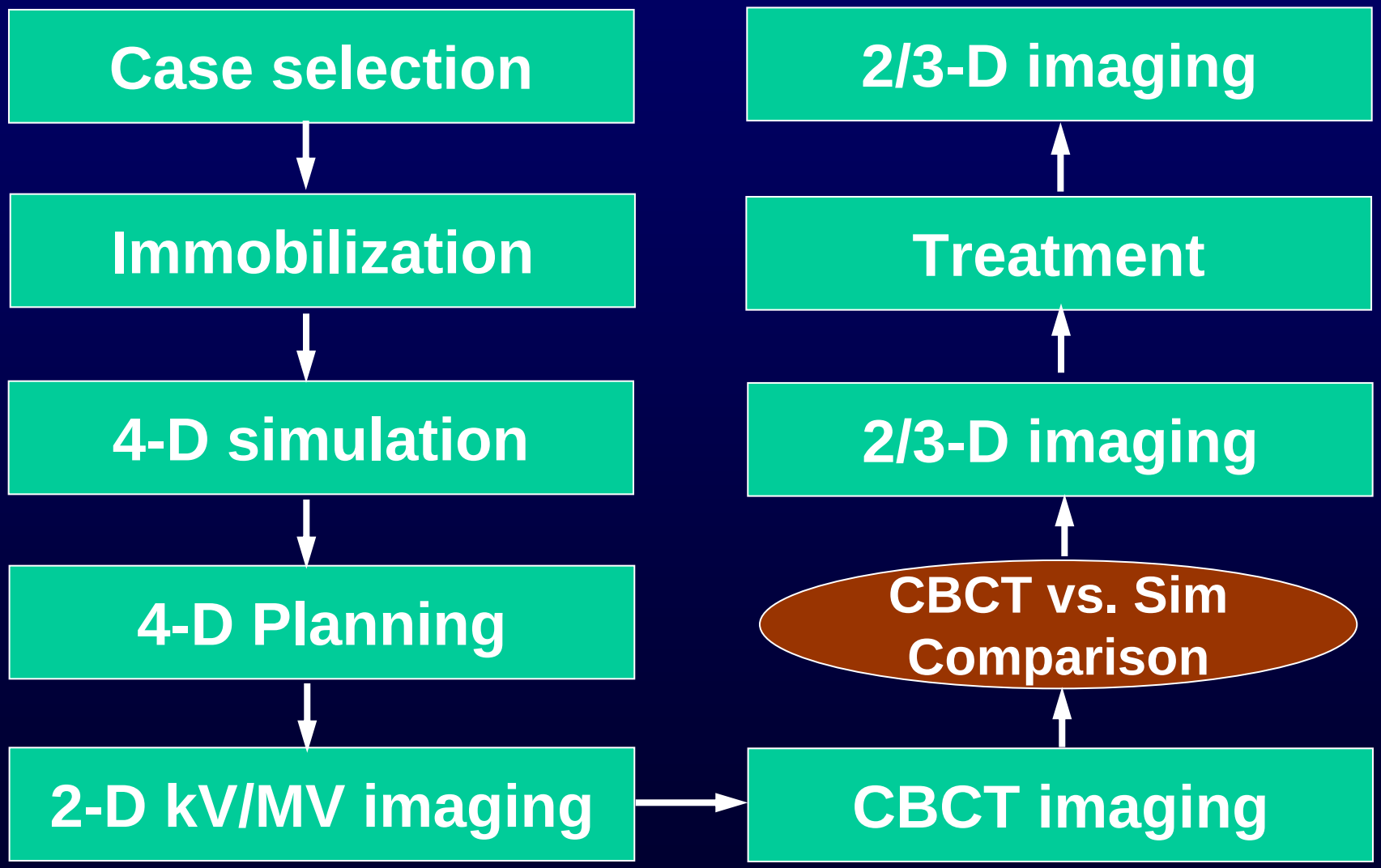
Bowsher, Yin et al, AAPM/ASTRO 2006

Summary

- In-room radiographic imaging is aimed to reduce margin from CTV to PTV
- It is one component of IGRT
- Patient information management is critical for modern radiation therapy
- New challenges are emerging from better in-room imaging

An Example of IGRT Application

IGRT Case: CBCT-Guided SBRT

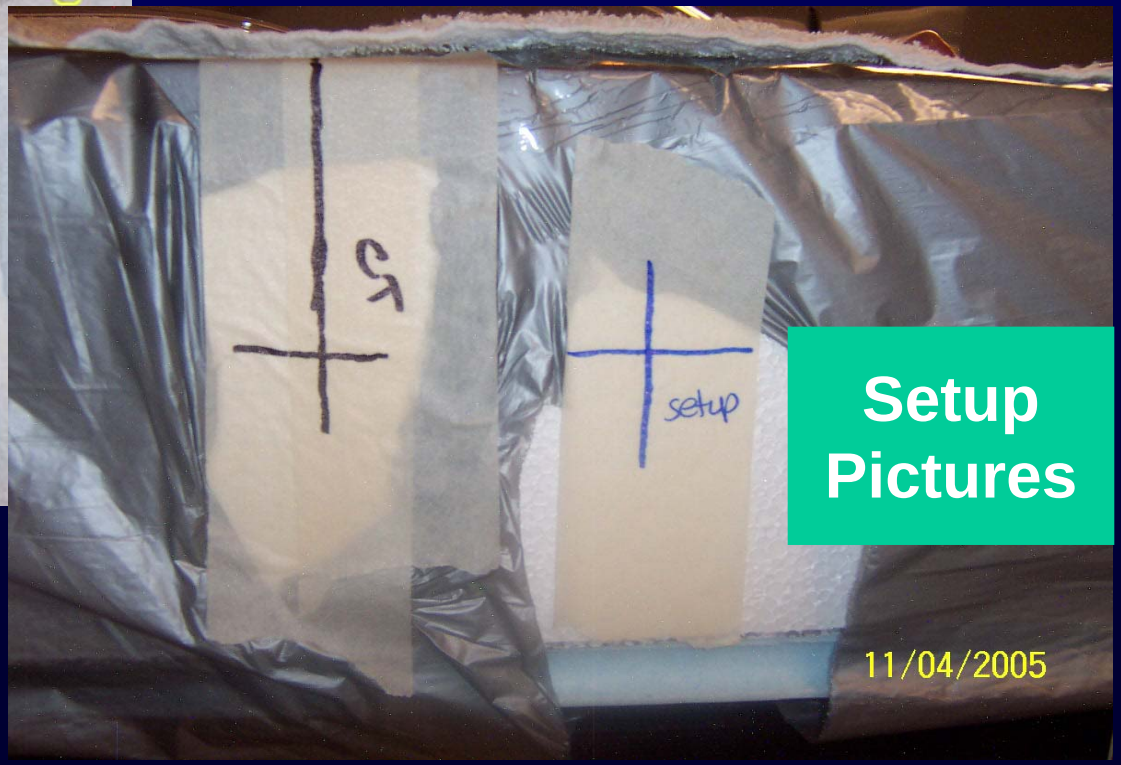


Yin et al ASTRO 2006

Para-spinal Case

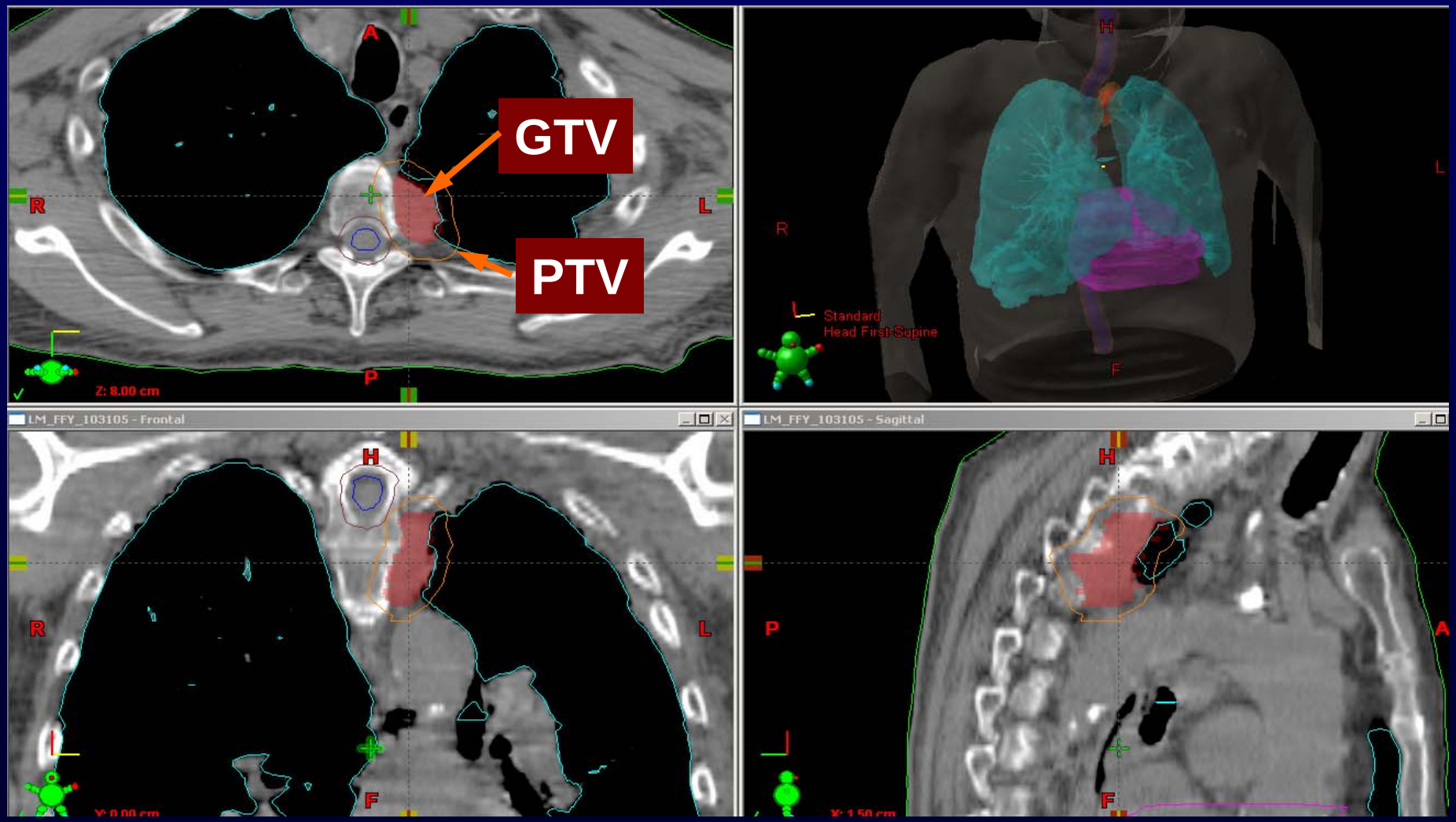
- Diagnosis
  - Paraspinal lung met (previously treated)
- GTV = 12 cc
- PTV = GTV + 5 mm (37.3 cc)
- Prescription:
  - 10 Gy x 3 fractions
  - ~ 95 % to iso
- 6 co-planar IMRT fields (6X,15X)

Para-spine - Immobilization

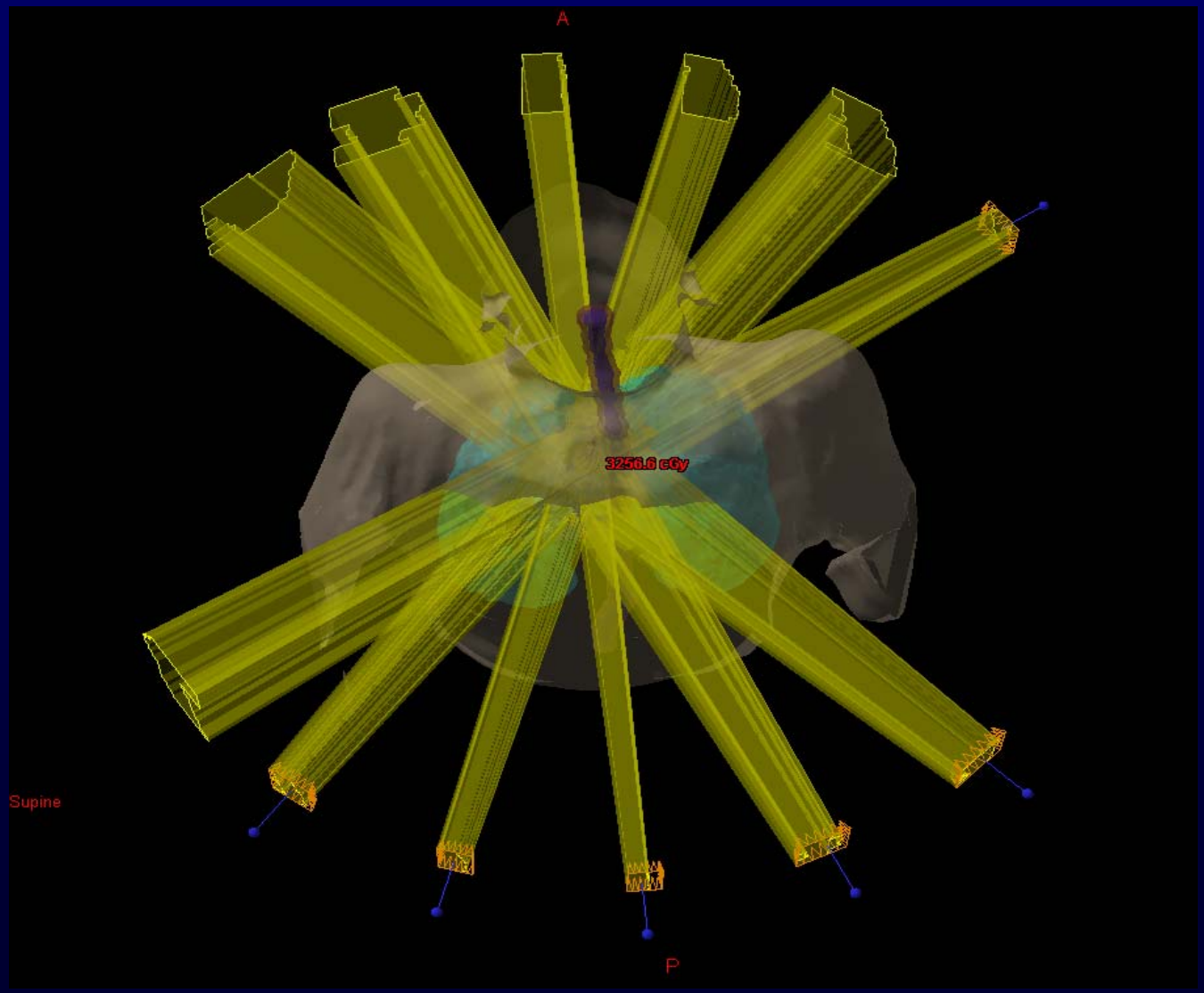


Setup Pictures

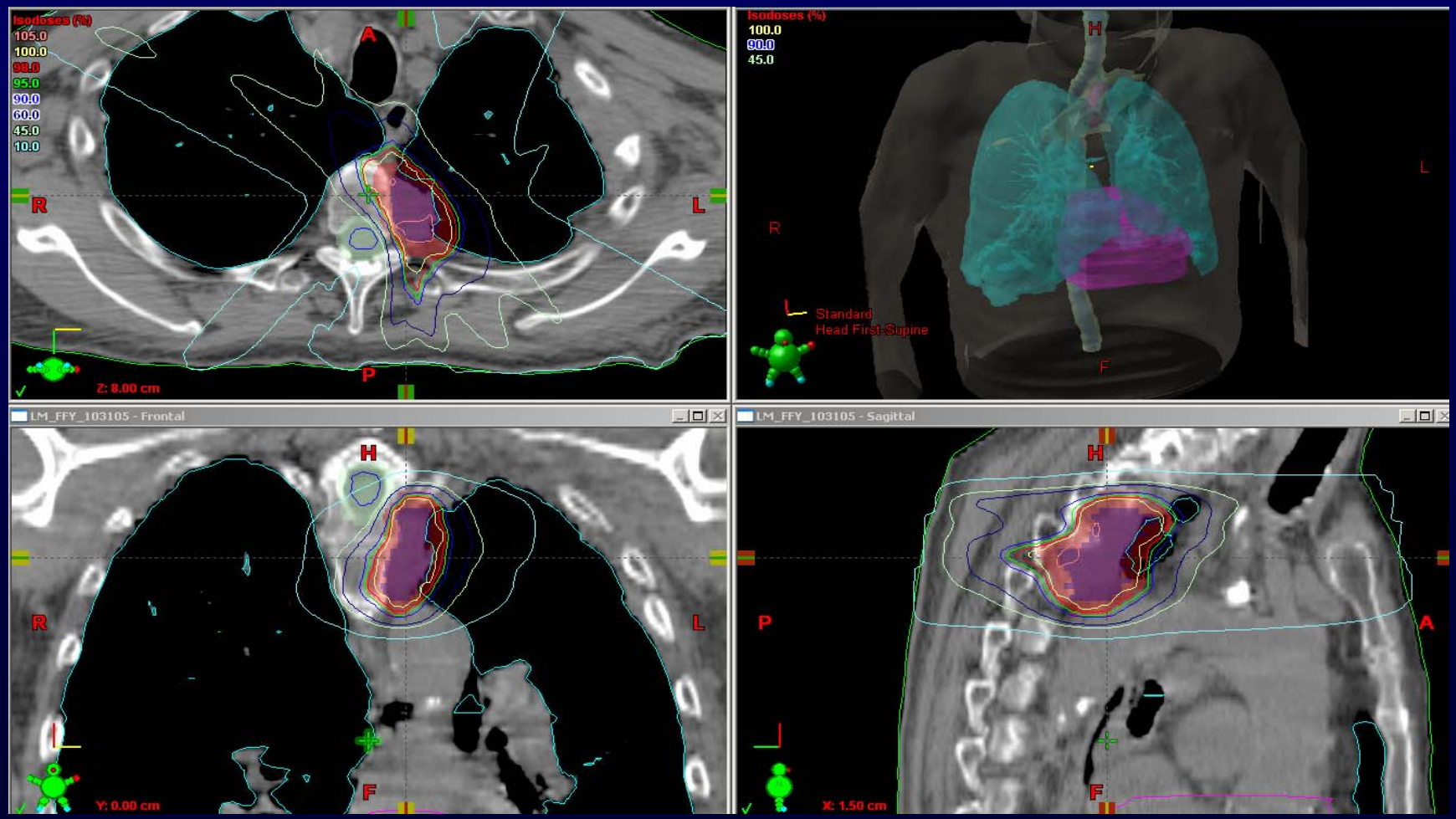
Treatment Volume



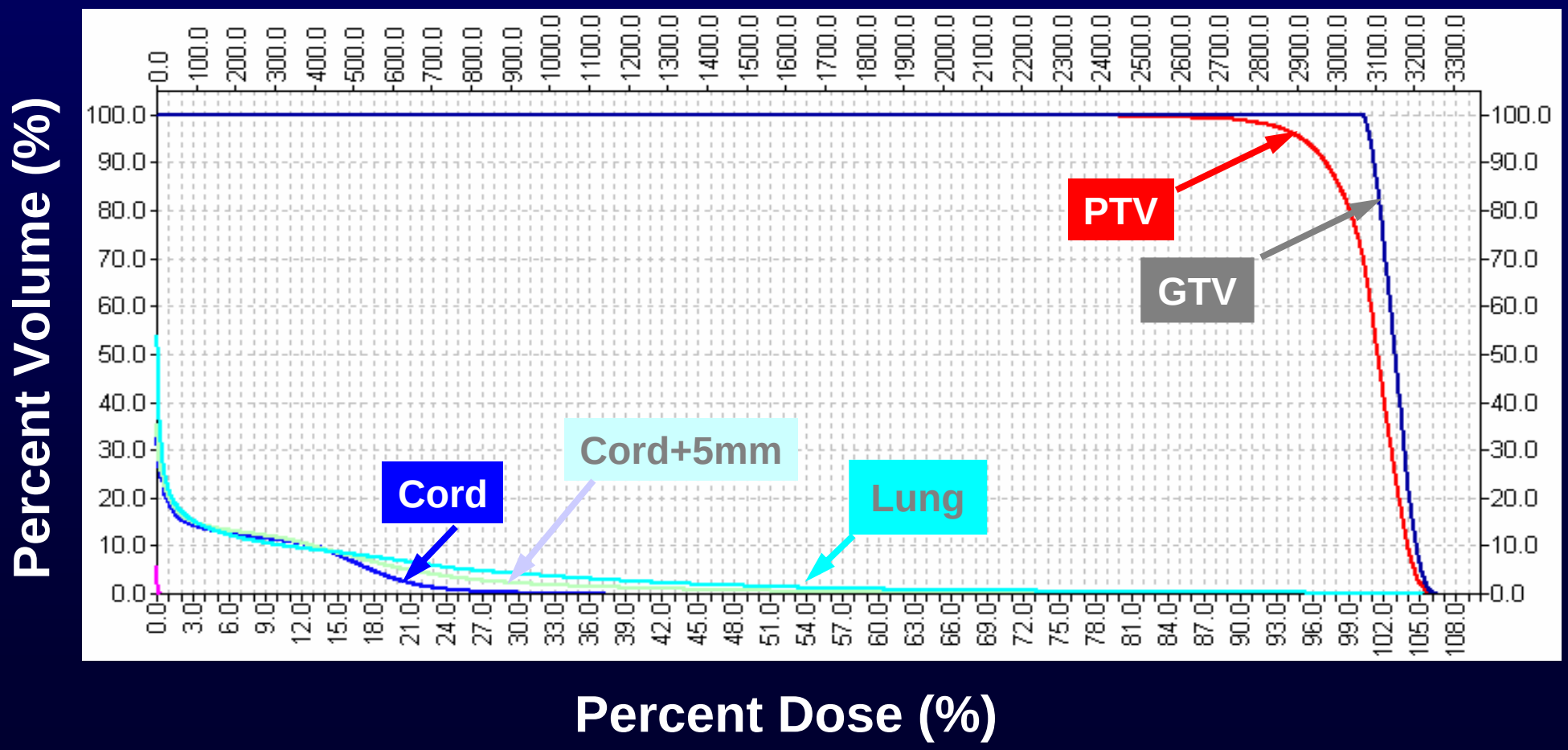
Beam Design



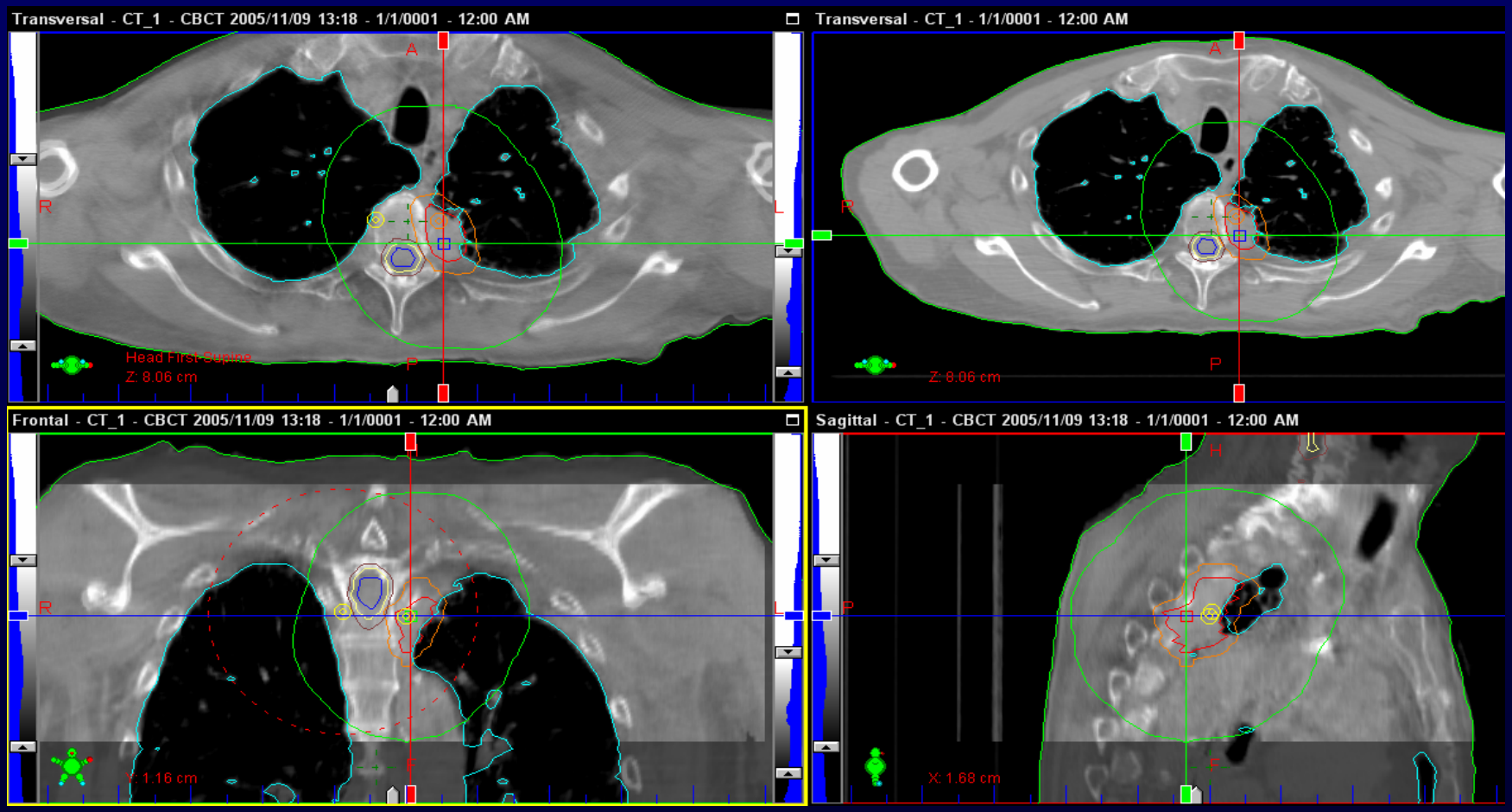
Iso-Dose Distribution



Planning Results

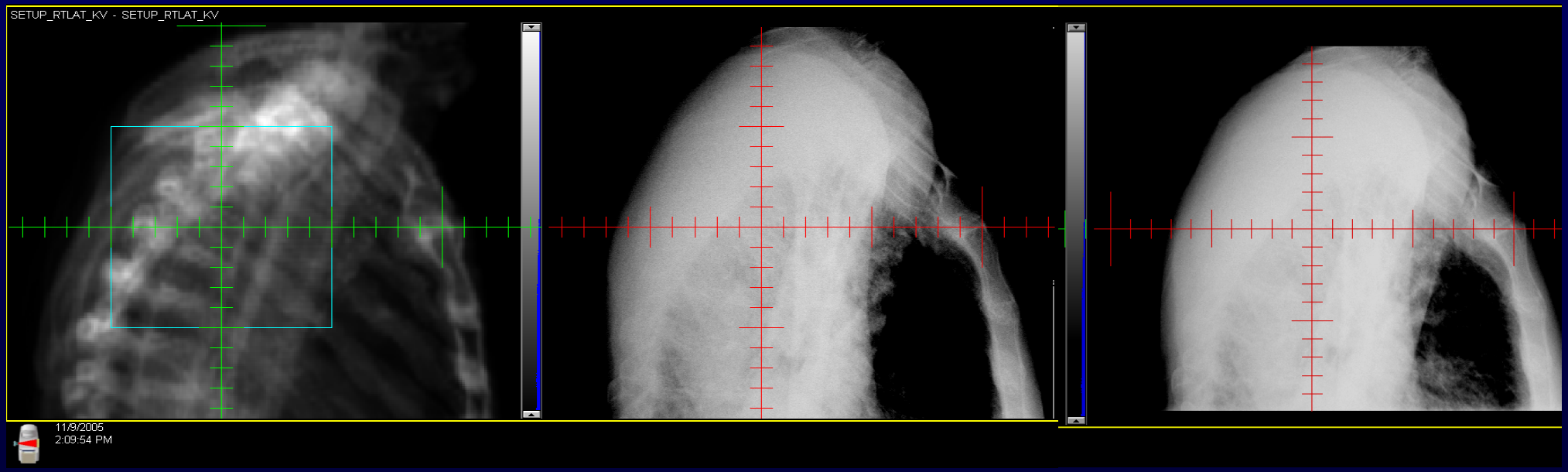


Pre-Treatment CBCT Localization



CBCT matching planning CT

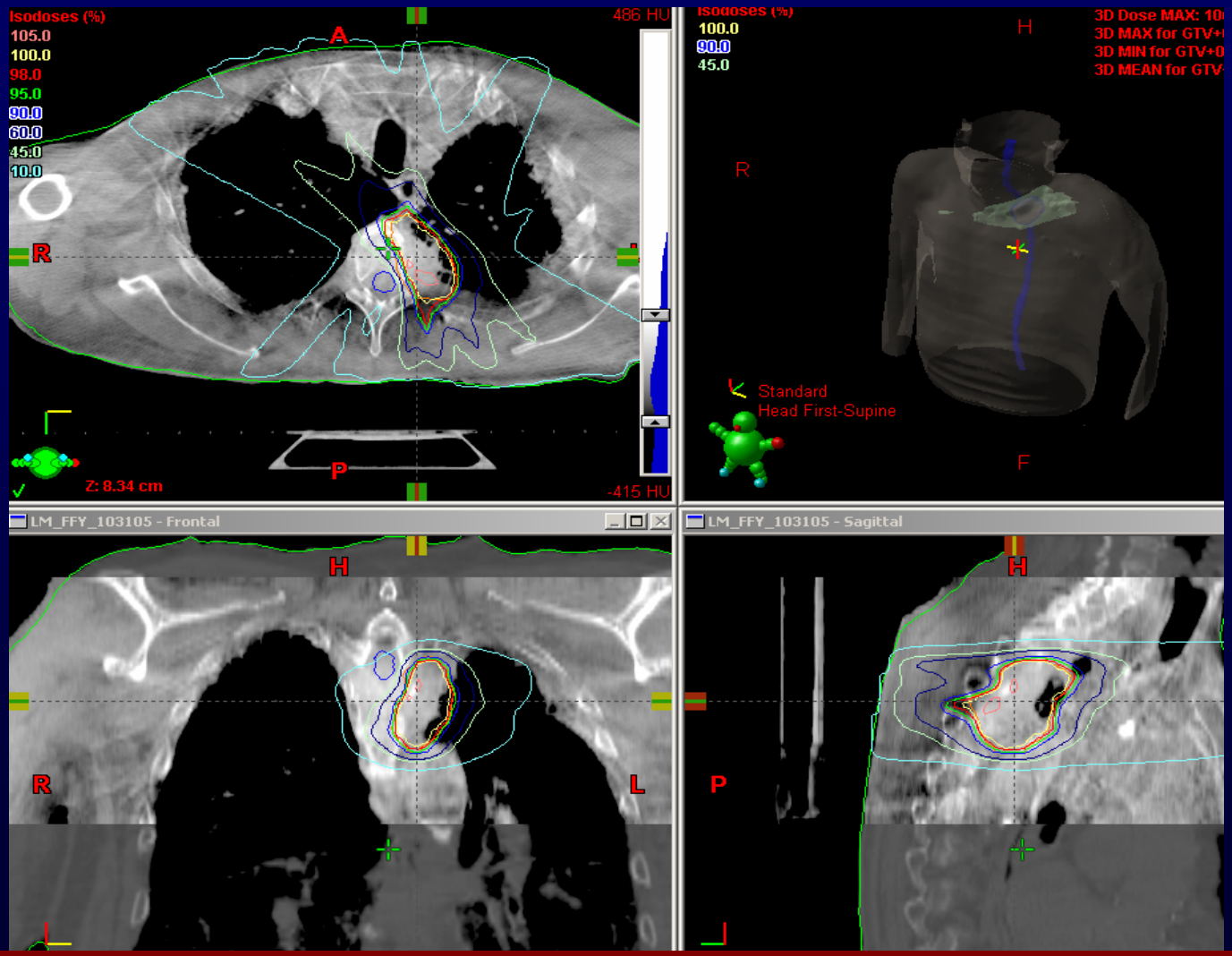
Treatment Accuracy



Reference **After treatment** **Before treatment**

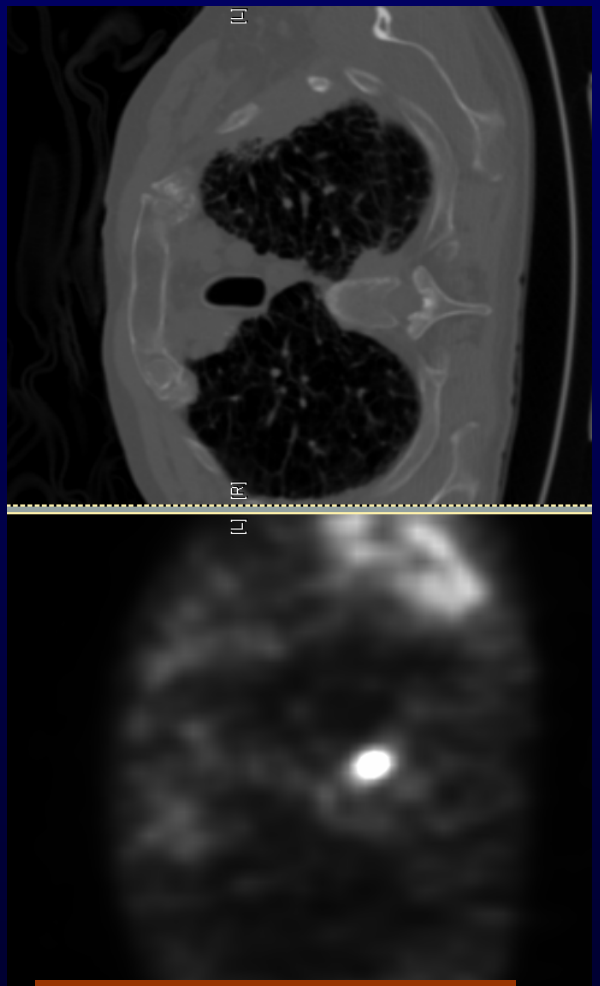
After CBCT and planning CT matching and patient shifting

Treatment Evaluation

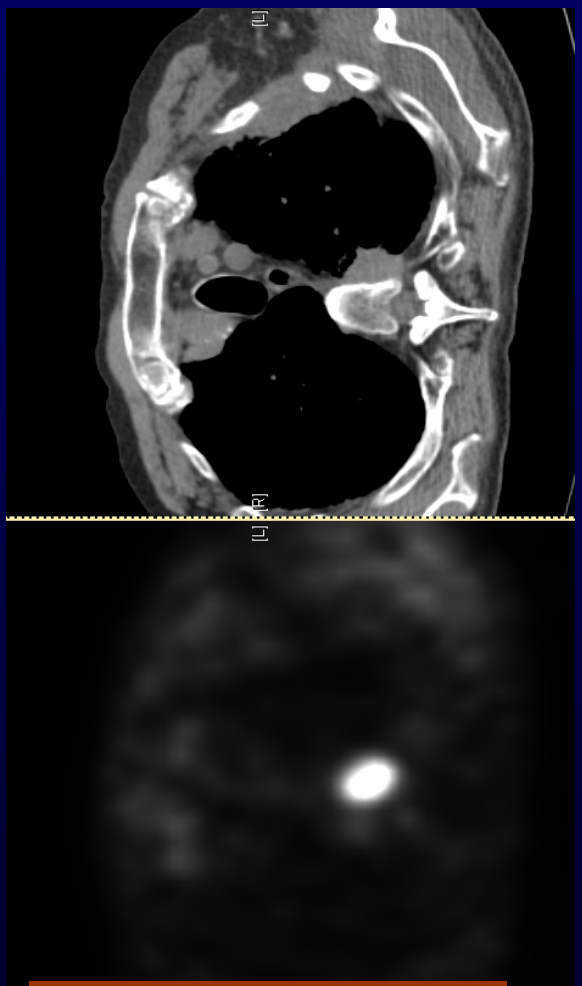


Fusing of planning CT and CBCT after treatment

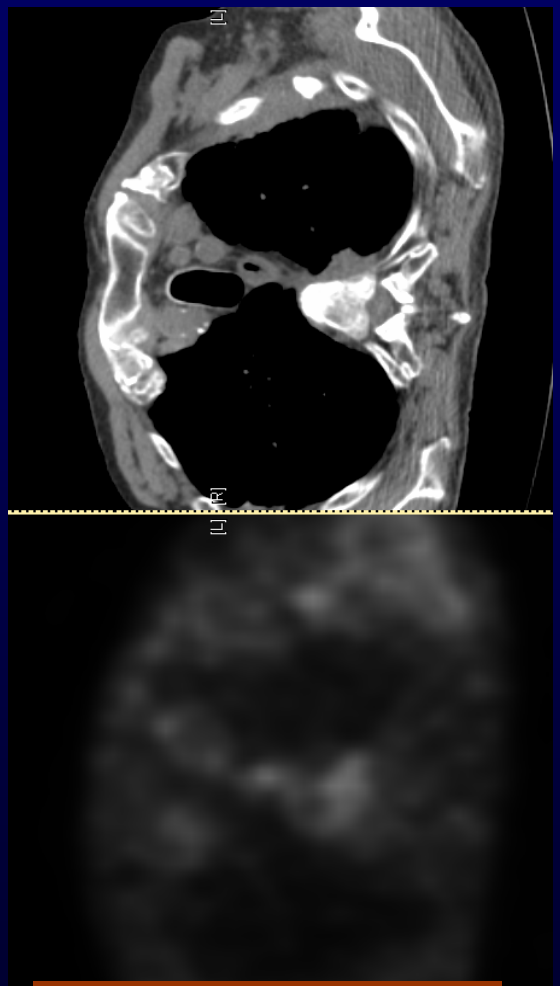
Treatment Follow-Up



Aug 2005 PET/CT

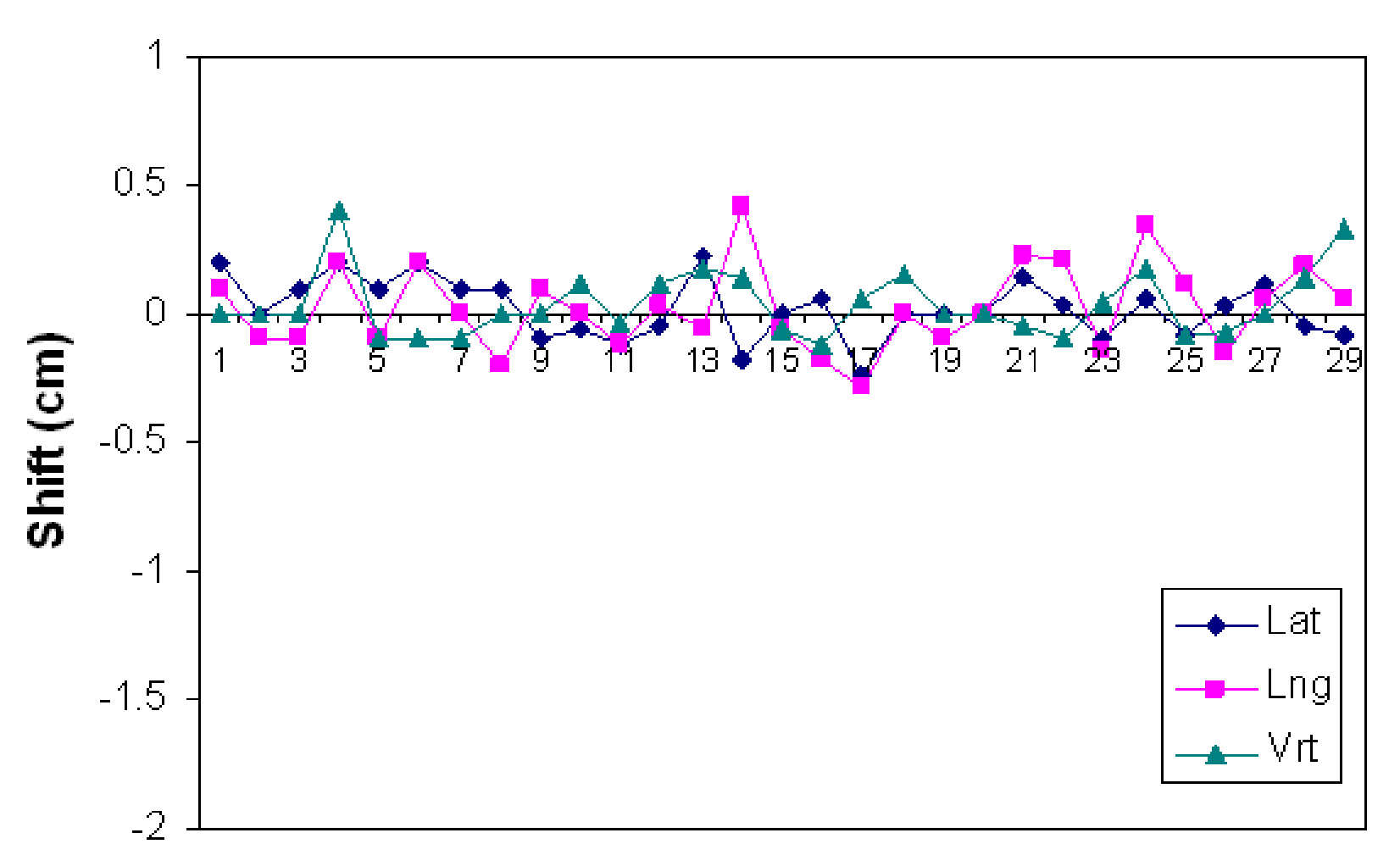


Nov 2005 PET/CT

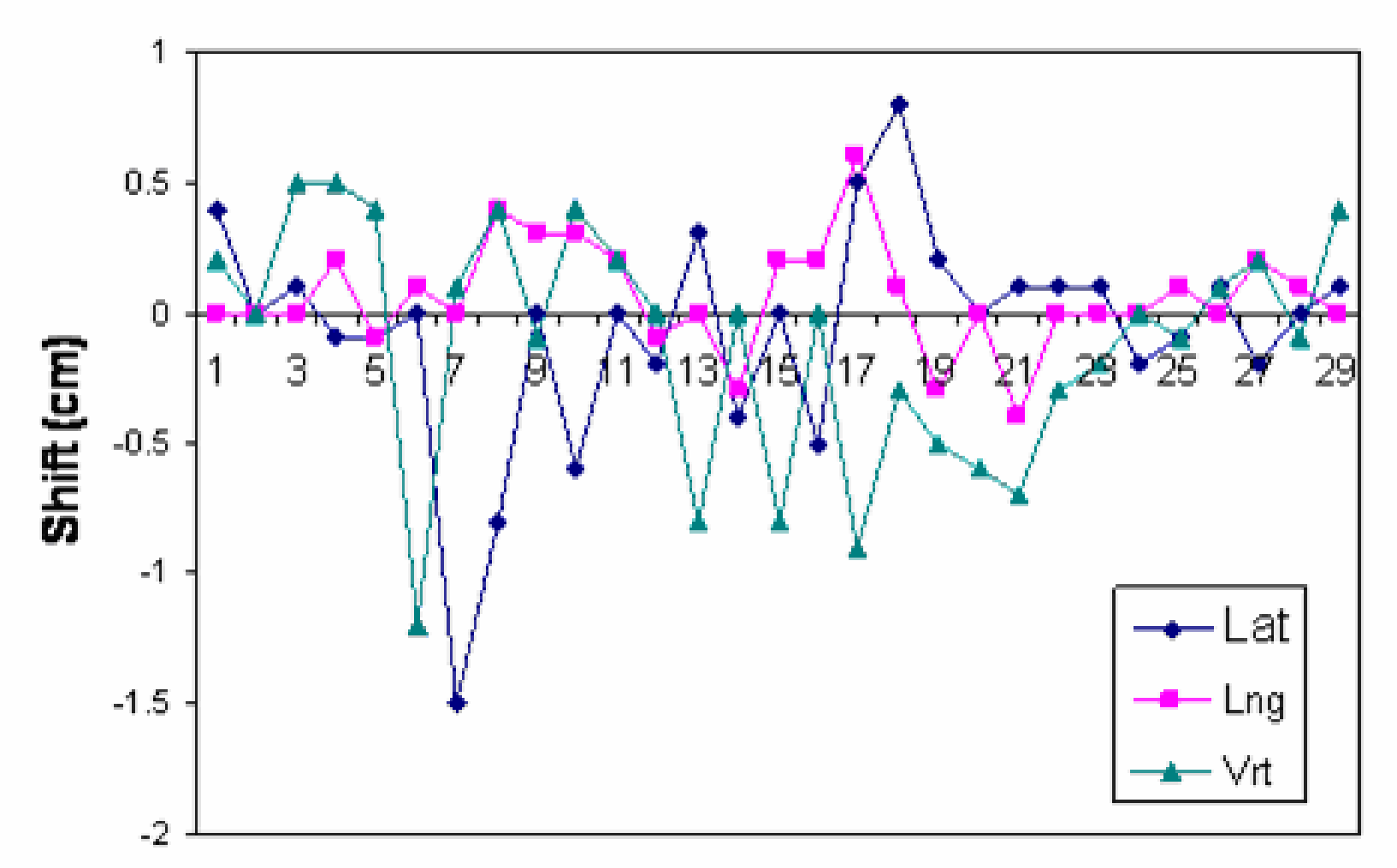


Jan 2006 PET/CT

Residual Errors between Pre- and Post-Treatment



Residual Error between 2-D Imaging and CBCT



Thanks

IGRT – An Integrated Process