In-Room Radiographic Imaging for Localization

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Acknowledgements

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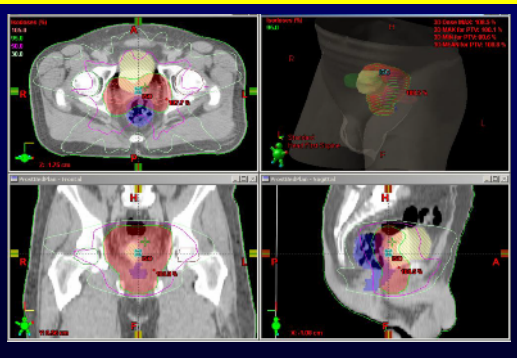
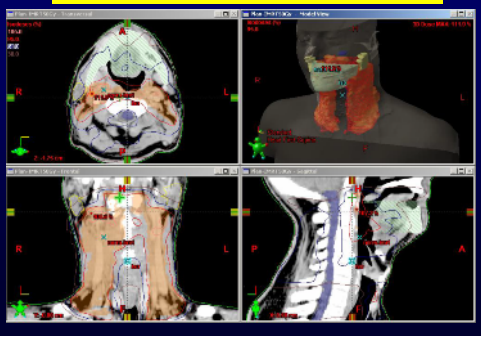
Outlines of the Talk

- 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	Precise but not accurate	Precise and accurate
IGRT	IMRT	IGRT+IMRT

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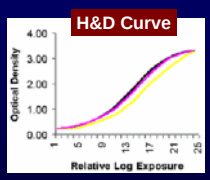
Imaging Methods

- 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

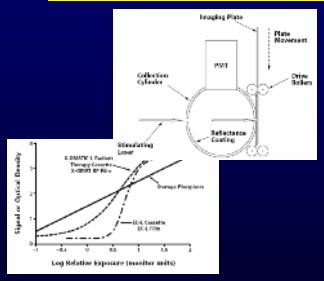
http://www.kodak.com/global/en/health/productsByType/onco/onco_Product.jhtml#products

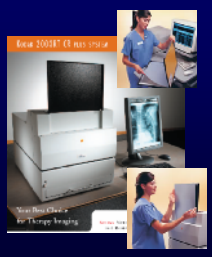
Examples of Film Imaging Systems

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

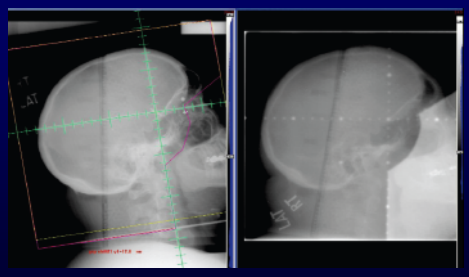




CR imaging principle **CR for sim., loc., veri.**

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**

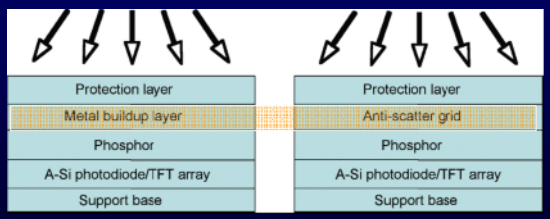
Digital MV X-ray Imaging

- 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

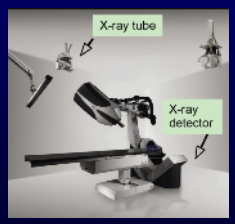
- Digital kV X-ray Imaging
  - *Room-Mounted System*
  - *Gantry-Mounted System*
  - *Mobile Systems*
- Amorphous Silicon (a-Si) technology

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

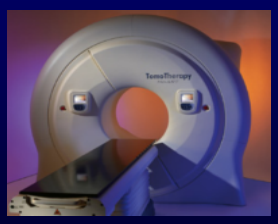
Varian Trilogy™ system

"Mobile" Systems

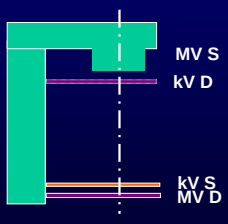
Varian ExaCT™ at MDACC

Siemens C-arm system

MV Tomographic Imaging

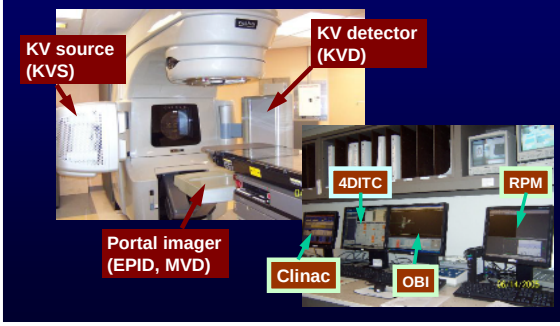


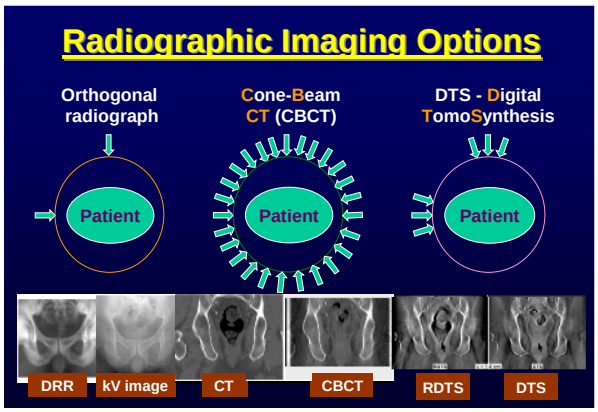
TomoTherapy Unit

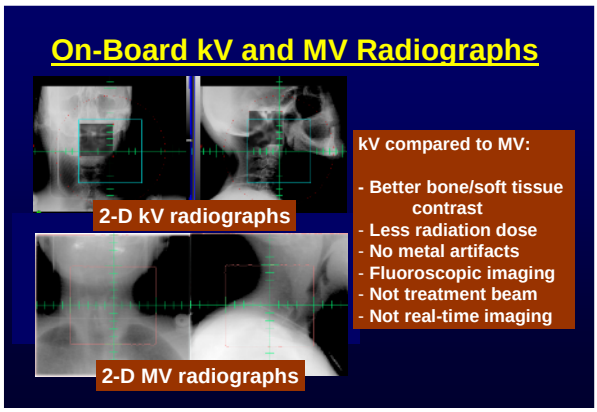


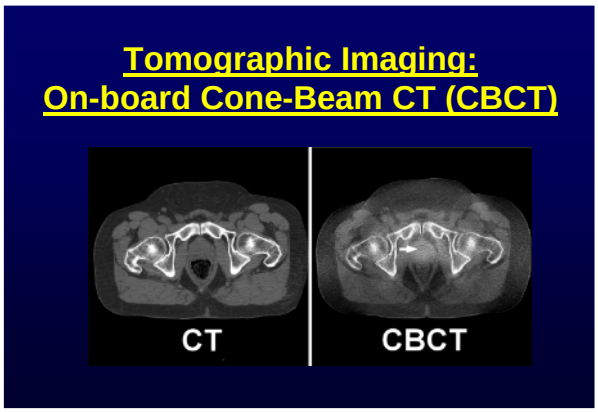
Siemens' system

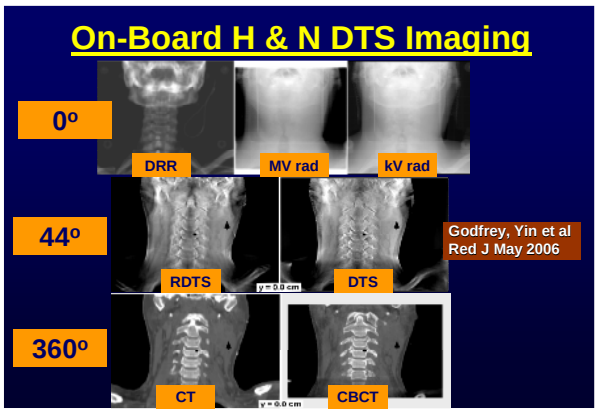
Duke On-Board Imager (OBI)




Radiographic Imaging Options
Orthogonal radiograph
Cone-Beam CT (CBCT)
DTS - Digital TomoSynthesis
Patient
Patient
Patient
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)
CT
CBCT


On-Board H & N DTS Imaging
0º
44º
360º
DRR
MV rad
kV rad
RDTS
DTS
CT
CBCT
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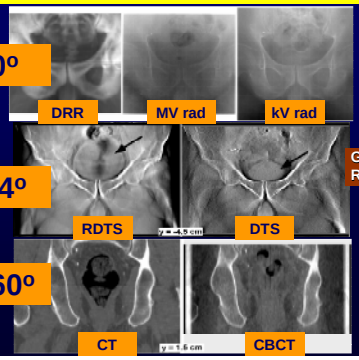
On-Board Prostate DTS Imaging



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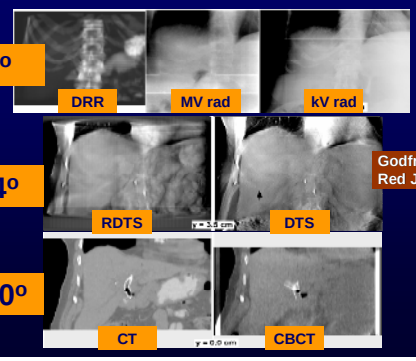
On-Board Liver DTS Imaging



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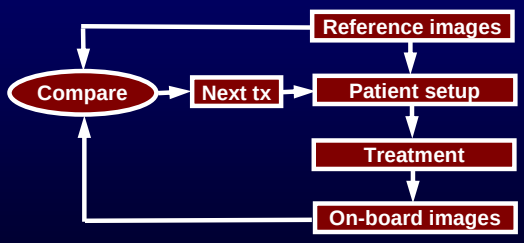
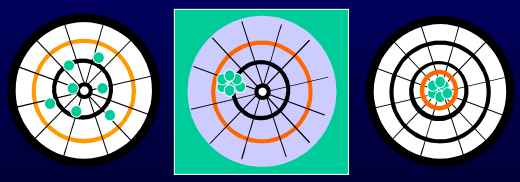
Clinical Applications

- 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

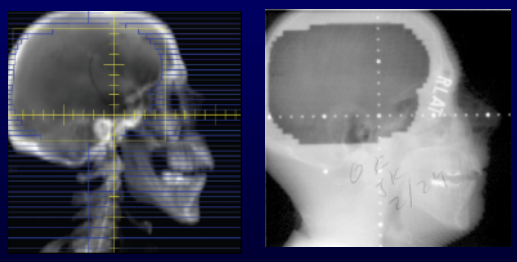


What Will Off-Line Verification Do for Precision and Accuracy?



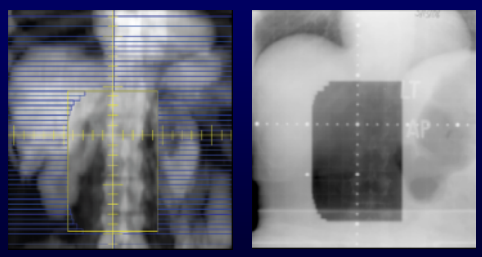
Random error | Systematic error | Systematic & Random error

Portal Field Verification



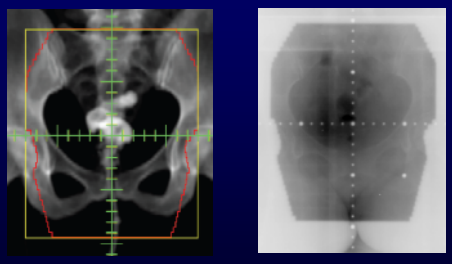
Reference image | Portal image

Portal Field Verification



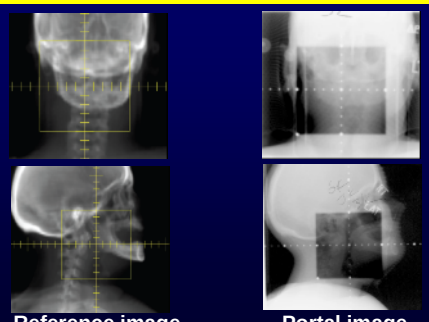
Reference image | Portal image

Portal Field Verification



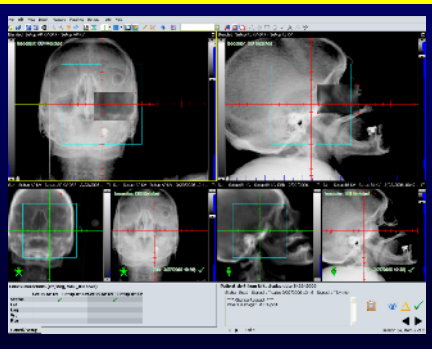
Reference image | Portal image

Isocenter Verification (MV/MV)

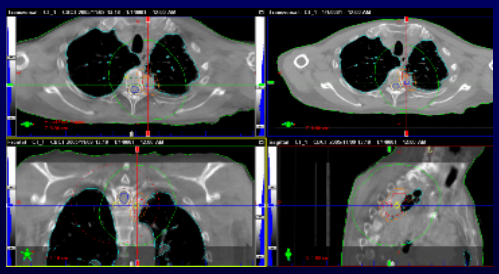


Reference image Portal image

Isocenter Verification (kV/kV)

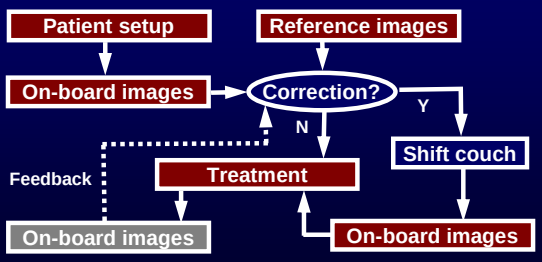


On-Board CBCT for Soft Tissue

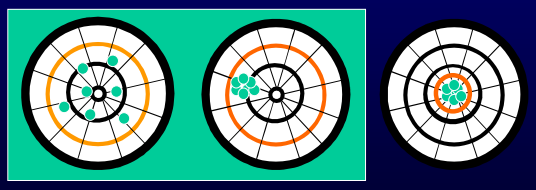


Reference image Portal image

On-Line Portal Verification

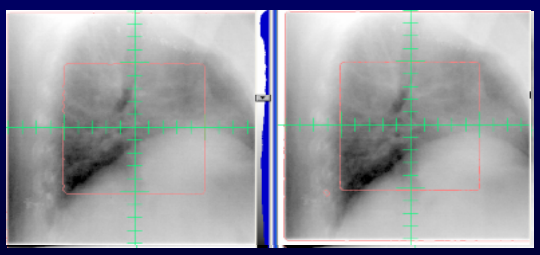


What Will On-Line Verification Do for Precision and Accuracy?



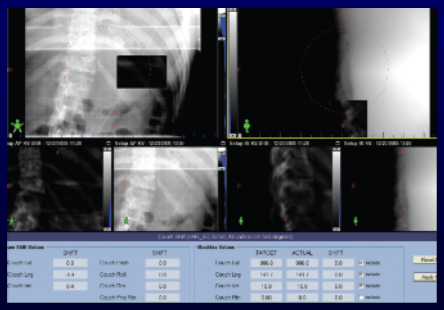
Random error | Systematic error | Systematic & Random error

On-Line Localization – MV/MV

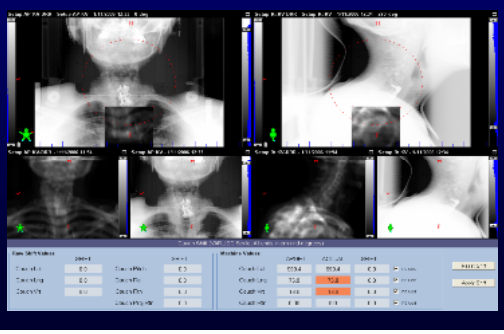


Before beam-on | After treatment

On-Line Localization kV/kV



On-Line Localization - kV/MV



Planning CT and On-Board CBCT

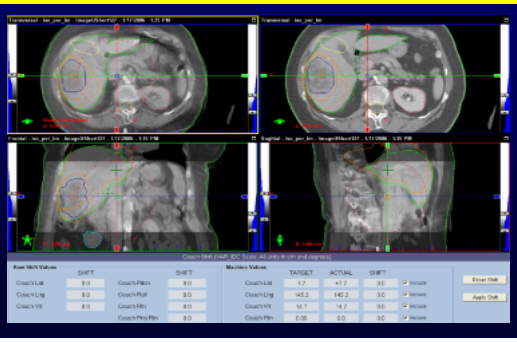


Image Fusion

- 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

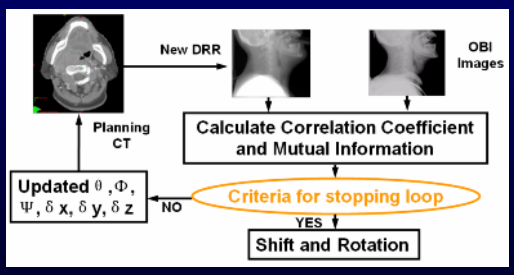


Image Fusion – 2D to 3D

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

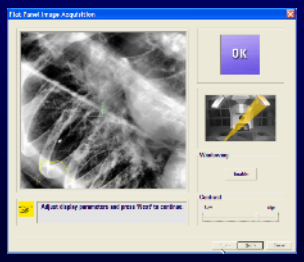


Image Fusion – 3D to 3D

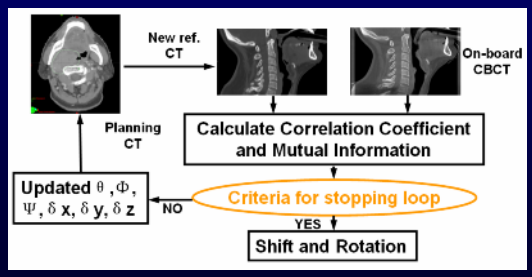
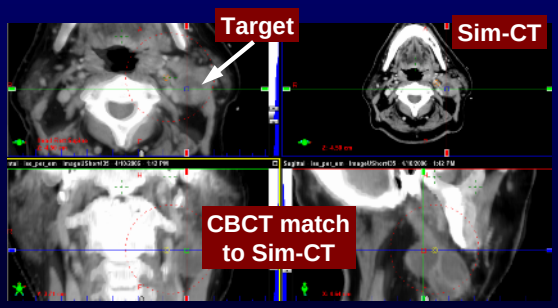


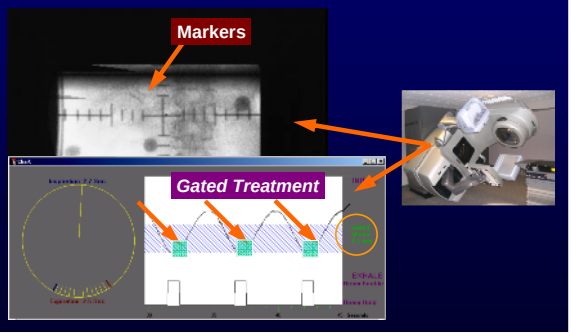
Image Fusion – 3D to 3D



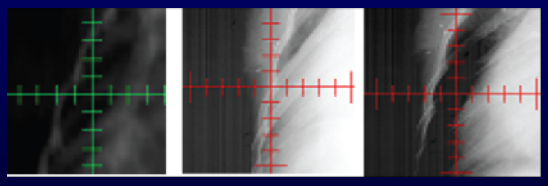
Imaging for Respiratory-Gated Treatment

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

4-D Fluoroscopic Imaging

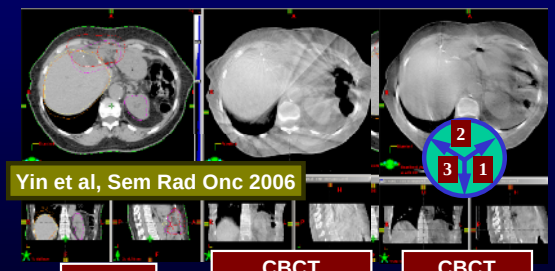


Breath-Hold Treatment Localization



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

Breath-Hold CBCT and Treatment



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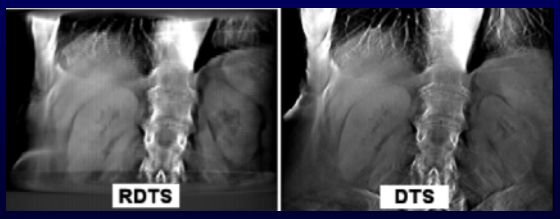
Sim CT

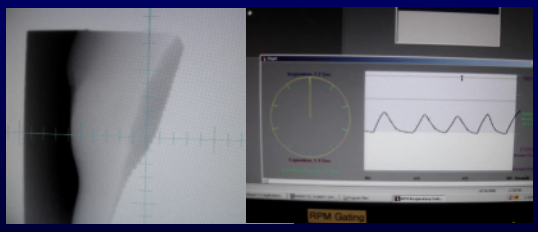
CBCT Free-breathing

CBCT Breath hold

Breath-Hold Digital Tomosynthesis

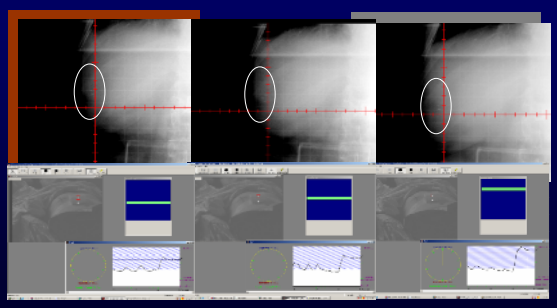


Breath Real-Time Portal Verification

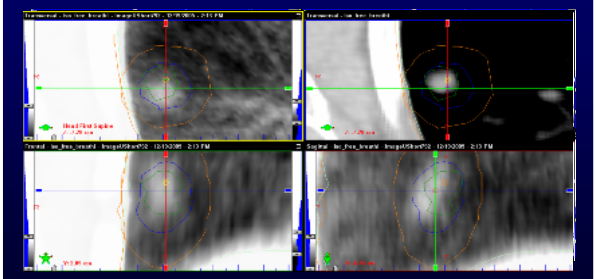


20 portal images in cine mode with < 1 s interval

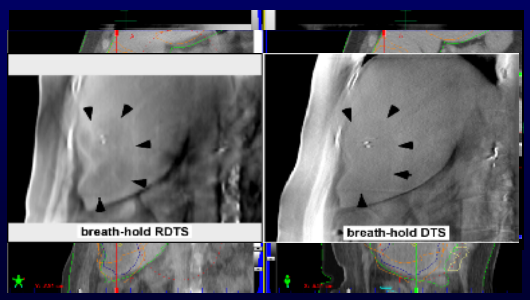
Liver - Effect of Breath-Hold



Free-Breath ITV Verification with CBCT



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

Example of QA Protocol

Table 3: Summary of QA recommendations for cone-beam kVCT on a linac. Tolerances may change according to expectations, experience and performance.

Frequency	Procedure	Tolerance
Daily or		Detector stability and system performance
each use		Dark image calibration acquisition before each scan
Geometric		
Localizing lasers		< 1 mm
Simple test object		< 1 mm
Motion and deployment of components		< 1 mm
Safety		
Interlocks: interrupts or prevents irradiation		Functional
Warning lights		Functional
Warm-up		
Generator operation		Functional
Detector operation		Functional
Detector signal		Within expected range
Collimator operational		Functional
Clinical process issues		
Database integrity		
Storage space availability		
Monthly or		Imaging system performance
year	Gain stability	Replace / refresh

S Yoo et al AAPM 2006

Other Considerations

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

Planning Images

CT images:	0.514 MB/image
MR images:	0.188 MB/image
PET images:	0.034 MB/image

Localization Images

kV image:	1.54 MB (1024x768x2)
MV image:	0.386 MB (512x384x2)
DRR image:	0.514 MB (512x512x2)
CBCT images:	28 MB (55 x 0.512 MB)

Storage Requirements

Typical CT-based plan size: 50-200 MB

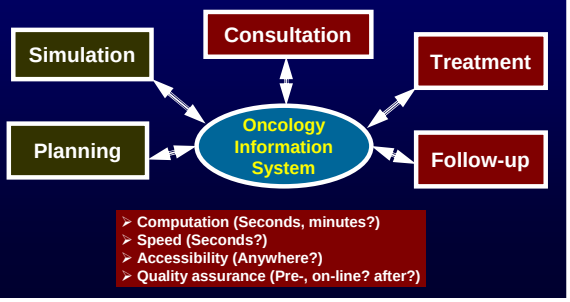
Typical IGRT patient fold size: 600MB-2GB

> 95% images:

Planning images including CT, MR, PET/CT, gated 4-D images, breath-hold CT

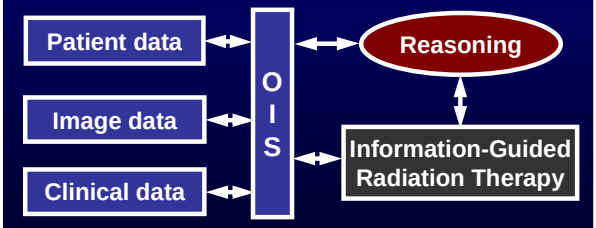
Verification images including: kV, MV, CBCT, cine, etc

Information Management: Departmental Integration

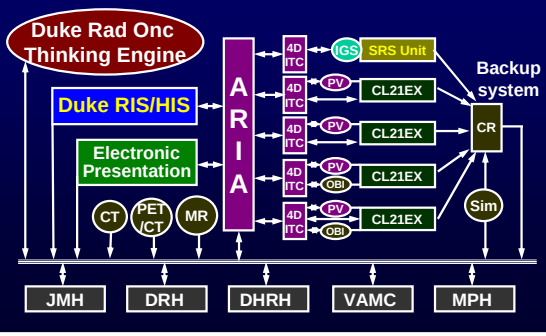


- Computation (Seconds, minutes?)
- Speed (Seconds?)
- Accessibility (Anywhere?)
- Quality assurance (Pre-, on-line? after?)

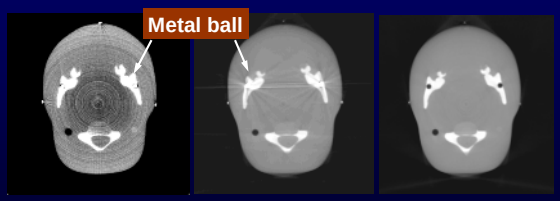
What Does IGRT Really Mean?



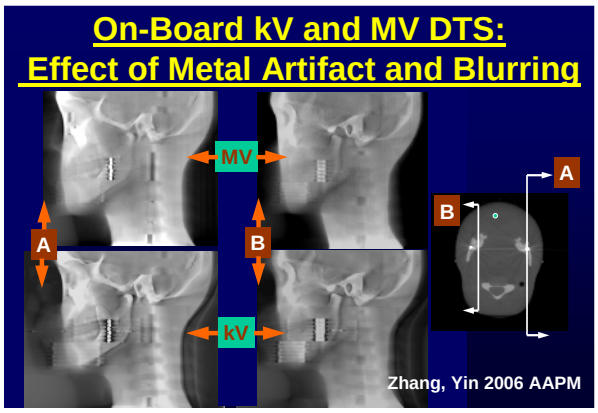
Planned Duke IGRT-2006

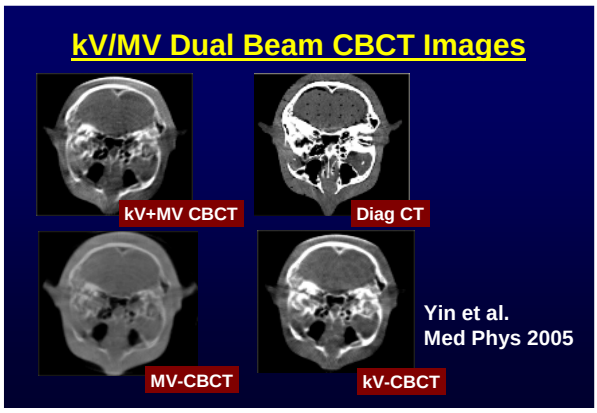


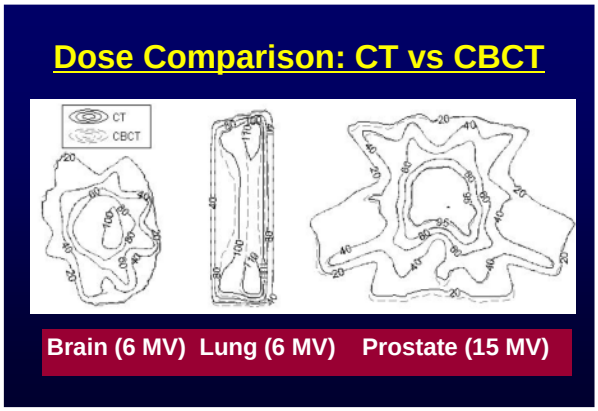
On-Board kV and MV CBCT: Effect of Metal Artifact and Blurring

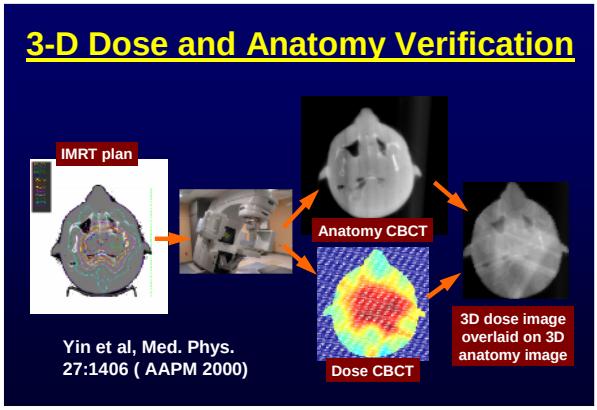


MV CBCT with metal ball | kV CBCT with metal ball | kV CBCT no metal ball

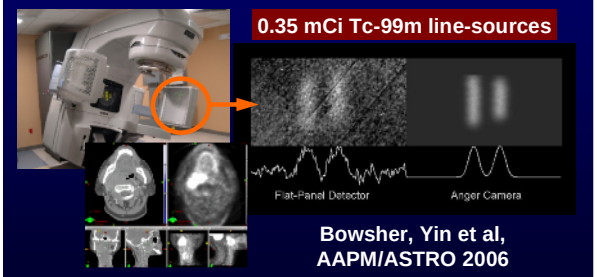

On-Board kV and MV DTS:
Effect of Metal Artifact and Blurring
MV
kV
A
B
A
B
Zhang, Yin 2006 AAPM


kV/MV Dual Beam CBCT Images
kV+MV CBCT
Diag CT
MV-CBCT
kV-CBCT
Yin et al.
Med Phys 2005


Dose Comparison: CT vs CBCT
CT
CBCT
Brain (6 MV) Lung (6 MV) Prostate (15 MV)


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



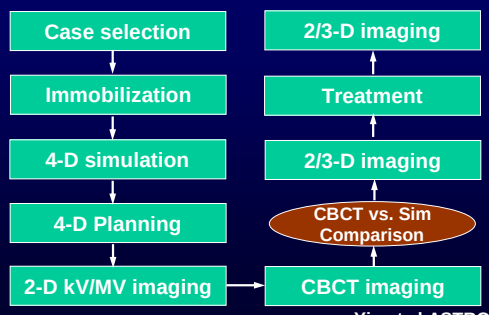
Bowsher, Yin et al, AAPM/ASTRO 2006

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



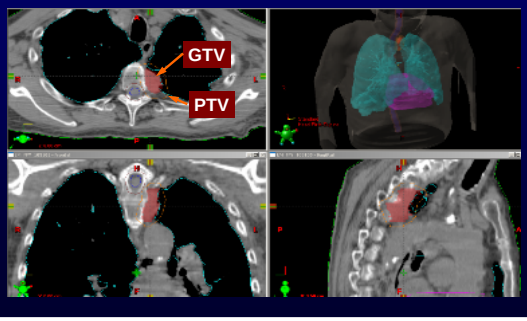
Yin et al ASTRO 2006

Para-spinal Case

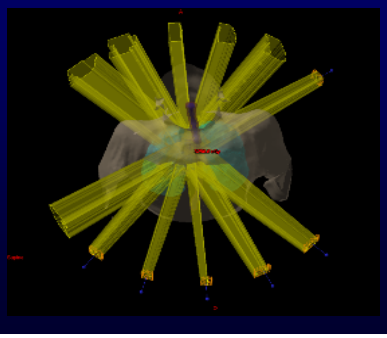
- Diagnosis
  - Paraspinal lung met (previously treated)
- GTV = 12 cc
- PTV = GTV + 5 mm (37.3 cc)
- Prescription:
  - 10 Gy x 3 fractions
  - ~ 95 % to iso
- 6 co-planar IMRT fields (6X,15X)

Para-spine - Immobilization

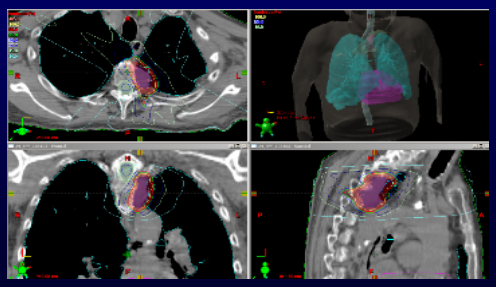
Treatment Volume



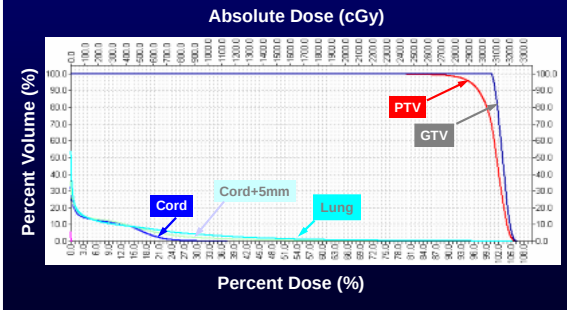
Beam Design



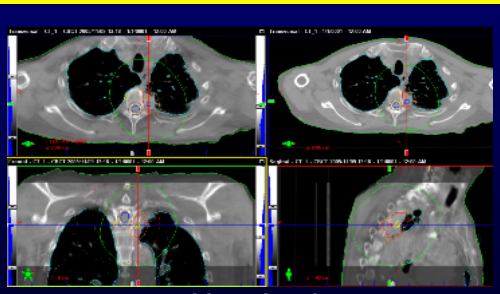
Iso-Dose Distribution



Planning Results

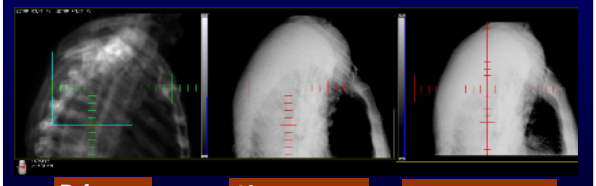


Pre-Treatment CBCT Localization



CBCT matching planning CT

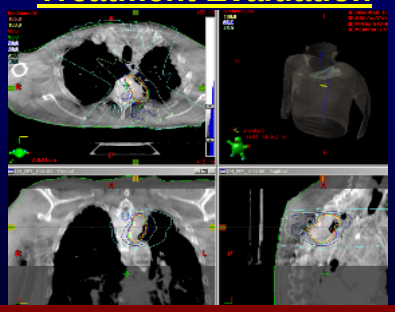
Treatment Accuracy



Reference | After treatment | Before treatment

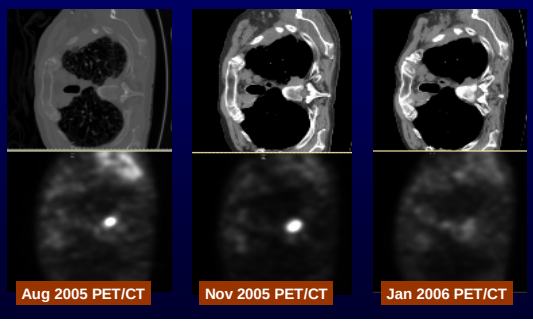
After CBCT and planning CT matching and patient shifting

Treatment Evaluation



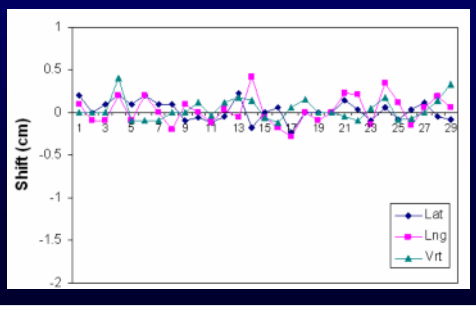
Fusing of planning CT and CBCT after treatment

Treatment Follow-Up

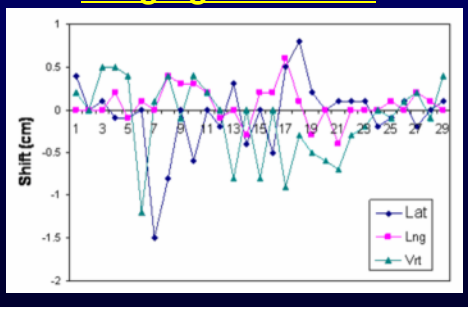


Aug 2005 PET/CT | Nov 2005 PET/CT | Jan 2006 PET/CT

Residual Errors between Pre- and Post-Treatment



Residual Error between 2-D Imaging and CBCT



Thanks