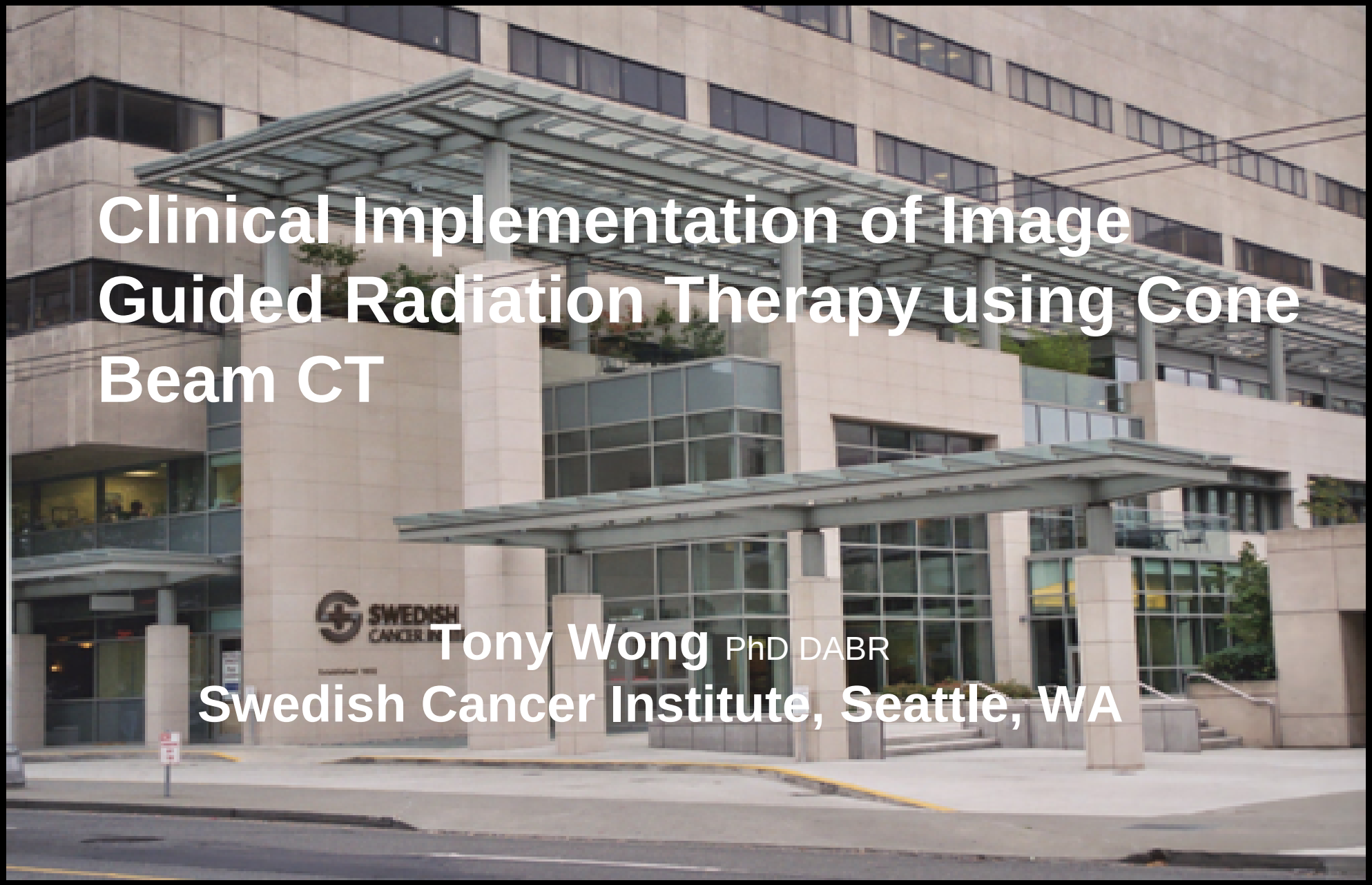


Clinical Implementation of Image Guided Radiation Therapy using Cone Beam CT

Tony Wong PhD DABR
Swedish Cancer Institute, Seattle, WA

Acknowledgements

- Vivek Mehta, MD
- Jin-song Ye, MS DABR
- Kent McCune, CMD
- Daliang Cao, PhD

Outline

- IGRT and benefits
- Elekta Synergy KV CBCT (XVI) platform
- KV CBCT patient dose
- CBCT Data transfer – Elekta XVI / CMS Xio
- IGRT clinical application
- Treatment / correction strategies

Image-Guided Radiation Therapy

Frequent imaging during a course of treatment as used to guide radiation therapy

(It is *distinct* from the imaging using different modalities to enhance target and organ delineation in the planning of radiation therapy)

Sources of Treatment Uncertainties

- **Setup uncertainty**
  - Patient position
- **Internal organ motion**
  - Target and/or normal tissues may change relative to skeletal anatomy
- **Organ deformation**
  - Variation in size and shape of the target and normal tissues

Benefits of IGRT

Improve precision and accuracy

- Optimize PTV margins and verification of target location
- Reduce treatment complication
- Improve tumor control with minimal toxicity

Adaptation

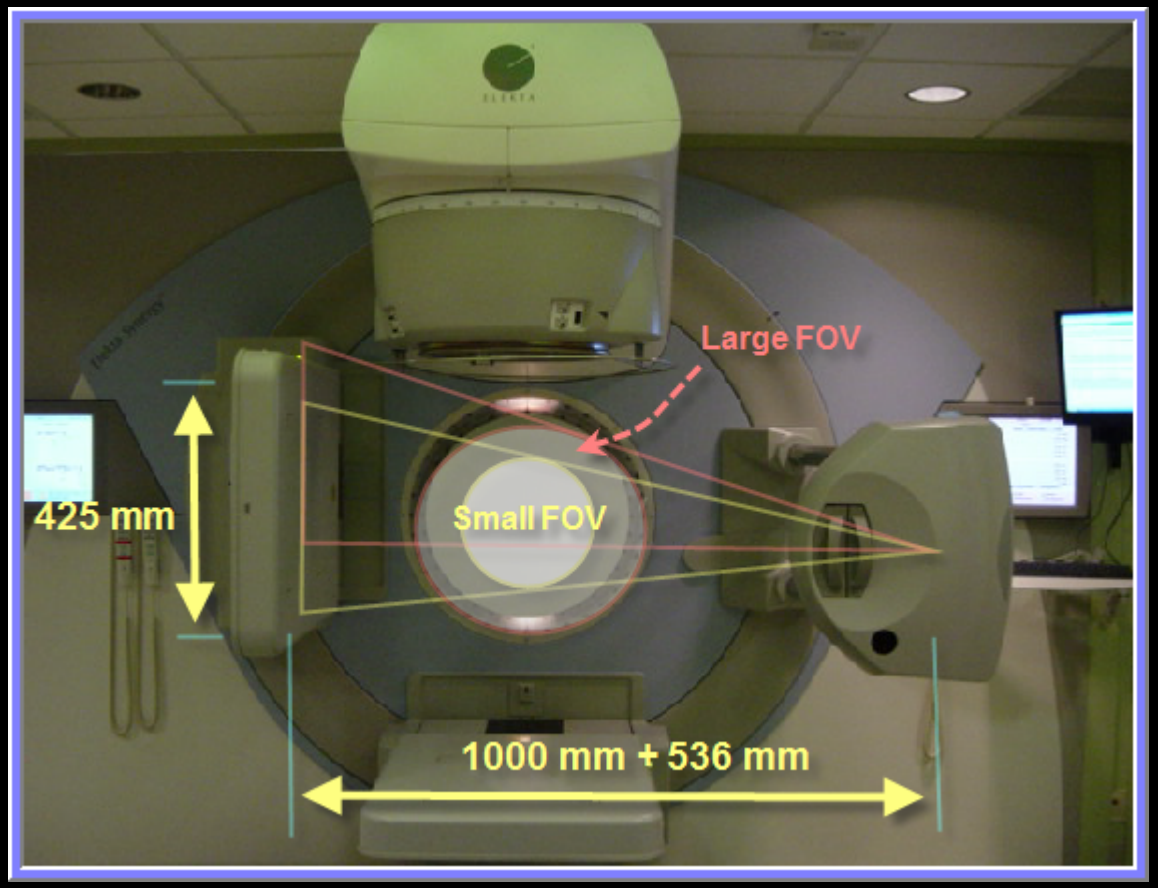
- Correct and moderate setup errors
- Assess anatomical changes / adaptive correction

Can also…

- Broaden application of RT
- Alter treatment scheme (dose escalation, hypo-fractionation…)

Elekta Synergy CBCT Platform

- **Small FOV = 27 cm**
  - Center of panel in line with KV isocenter
  - All the object is in the image; can do half revolution
- **Medium FOV = 41 cm**
  - Panel offset 11.5 cm from iso
  - Image quality better in center than the outside
  - Require full 360 degree revolution
- **Large FOV = 50 cm**
  - Edge of panel in line with iso
  - Half of object in each image
  - Require full 360 degree revolution



CBCT Scan Geometry

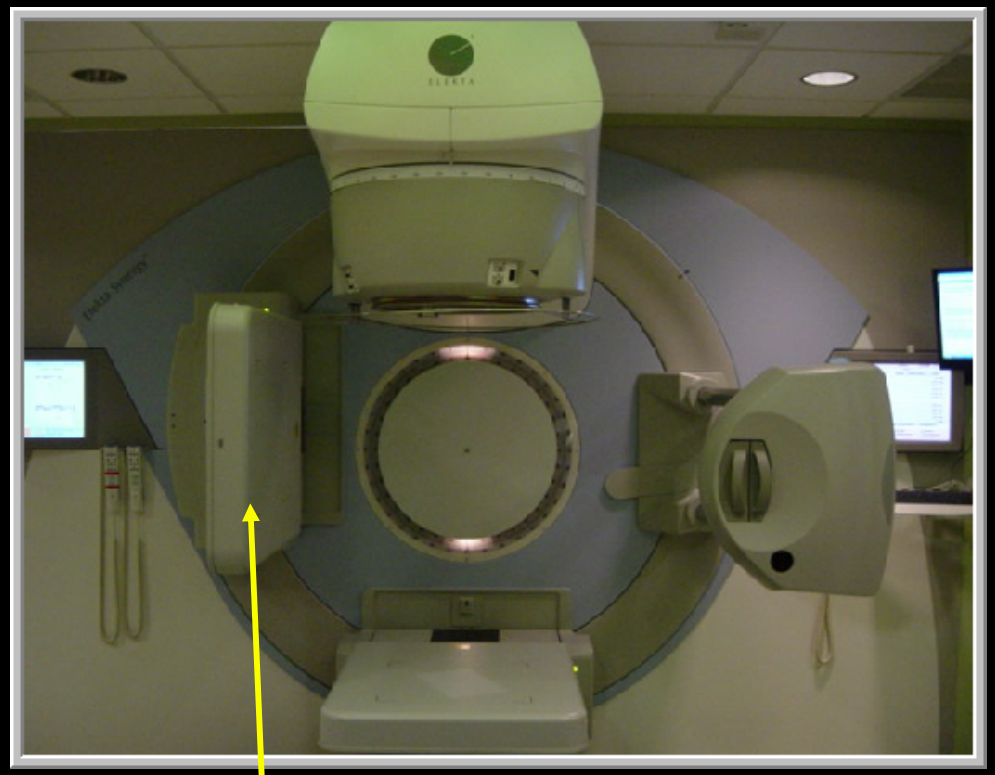
Collimator Label	FOV	Nominal Axial Length (cm)
S20	Small	26.0
M2	Medium	2.5
M10	Medium	12.0
M20	Medium	26.0
L2	Large	2.5
L10	Large	12.5
L20	Large	26.0

KVp, mA and ms

KVp	70 - 150
mA	ms 10 – 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100 ms 12 - 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100 ms 16 – 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100 ms 20 – 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100 ms 25 – 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100 ms 32 – 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100 ms 40 – 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100, 125, 160, 200, 250 ms 160 - 100, 125, 160, 200, 250, 320, 400, 500
ms	10, 12, 16, 20, 25, 32, 40, 160

CBCT Acquisition Geometry

- Full scan - 360 degree gantry rotation (Also allows half scan)
- ~ 5 frames per second
- ~ 2 min / gantry rotation (3.18°/s)
- Typical Exposure
  - 120 KVp
  - 25-100 mA
  - 10-40 ms
- 41 x 41 cm^2 FP image
  - 1024 x 1024 at 400 μm pixel pitch

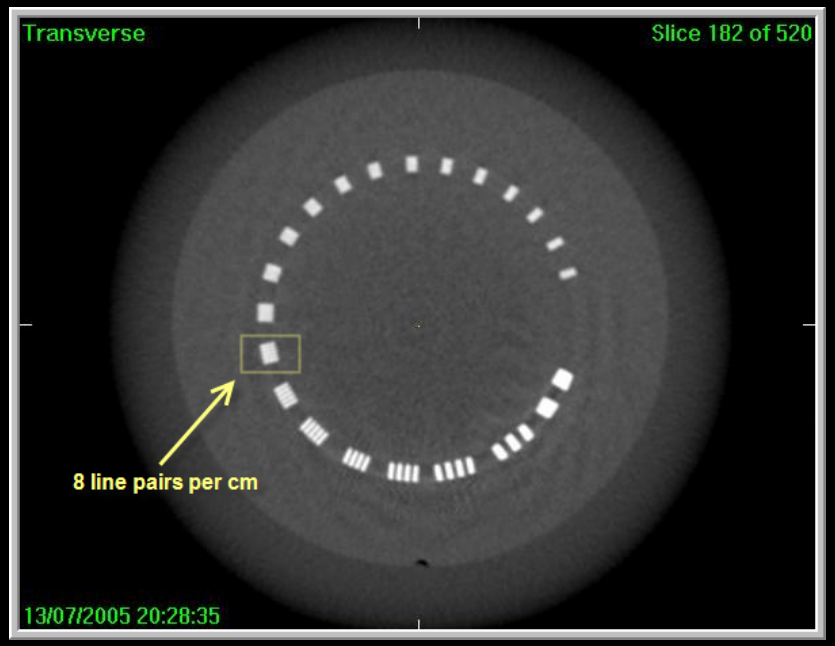


Offset detector allows larger FOV

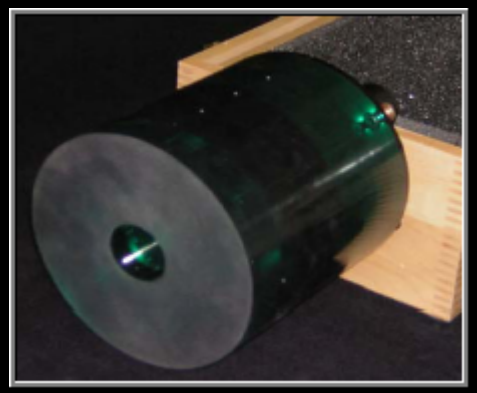
Grantry Mounted Cone-Beam CT

- **Features***
  - Soft tissue contrast
  - Patient imaged in the treatment position
  - Calibrated to machine MV isocenter
  - 3D isotropic spatial resolution ($\geq$ 7 lp/cm)
  - Geometrically precise ($\leq$ 1 mm)
- **Limitations***
  - Relative slow acquisition - about 2 minutes for a full scan
  - Not diagnostic quality
    - Ring, streak, ghost & radar artifacts
    - Cupping
    - Outline reduction effect

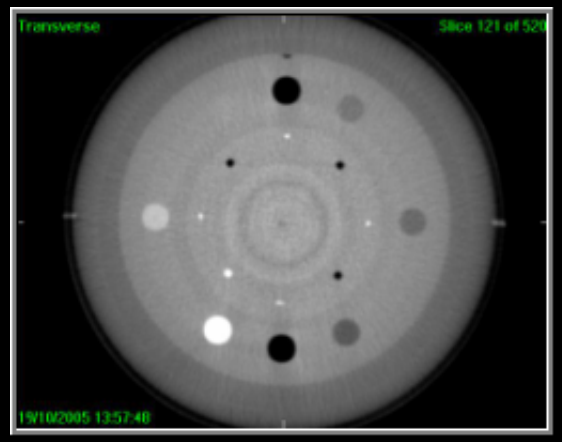
** Elekta Synergy System*



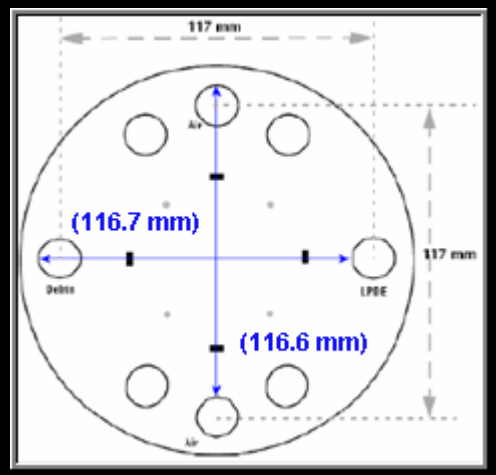
3D Spatial Resolution ≥ 7 lp/cm



Catphan® Phantom



Low contrast visibility ≤ 2%

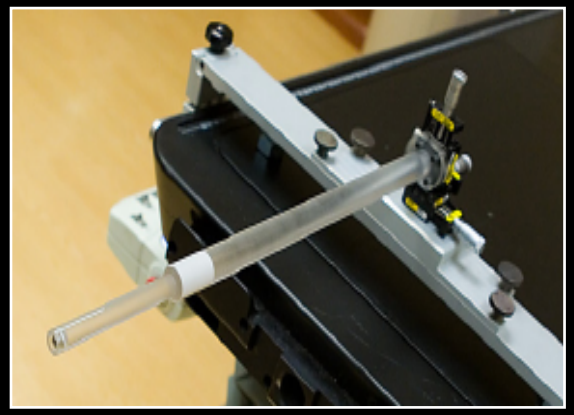


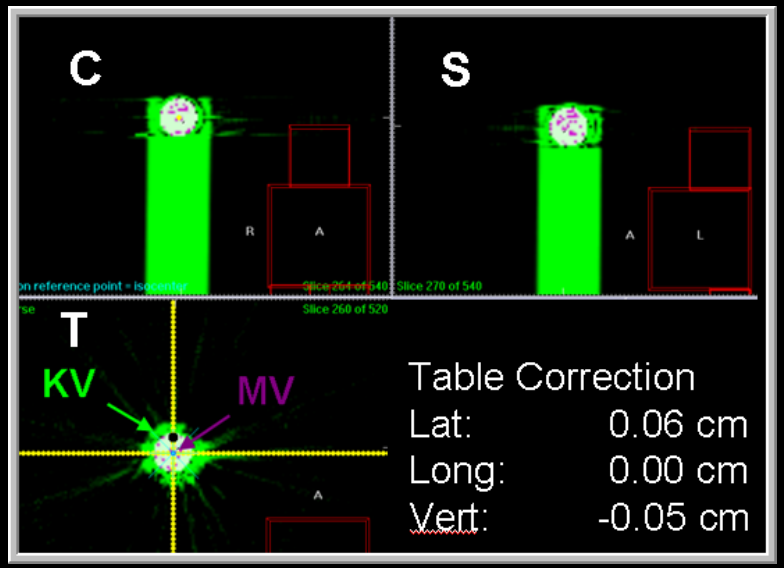
Transverse geometric accuracy ≤ 1mm

KV / MV Calibration

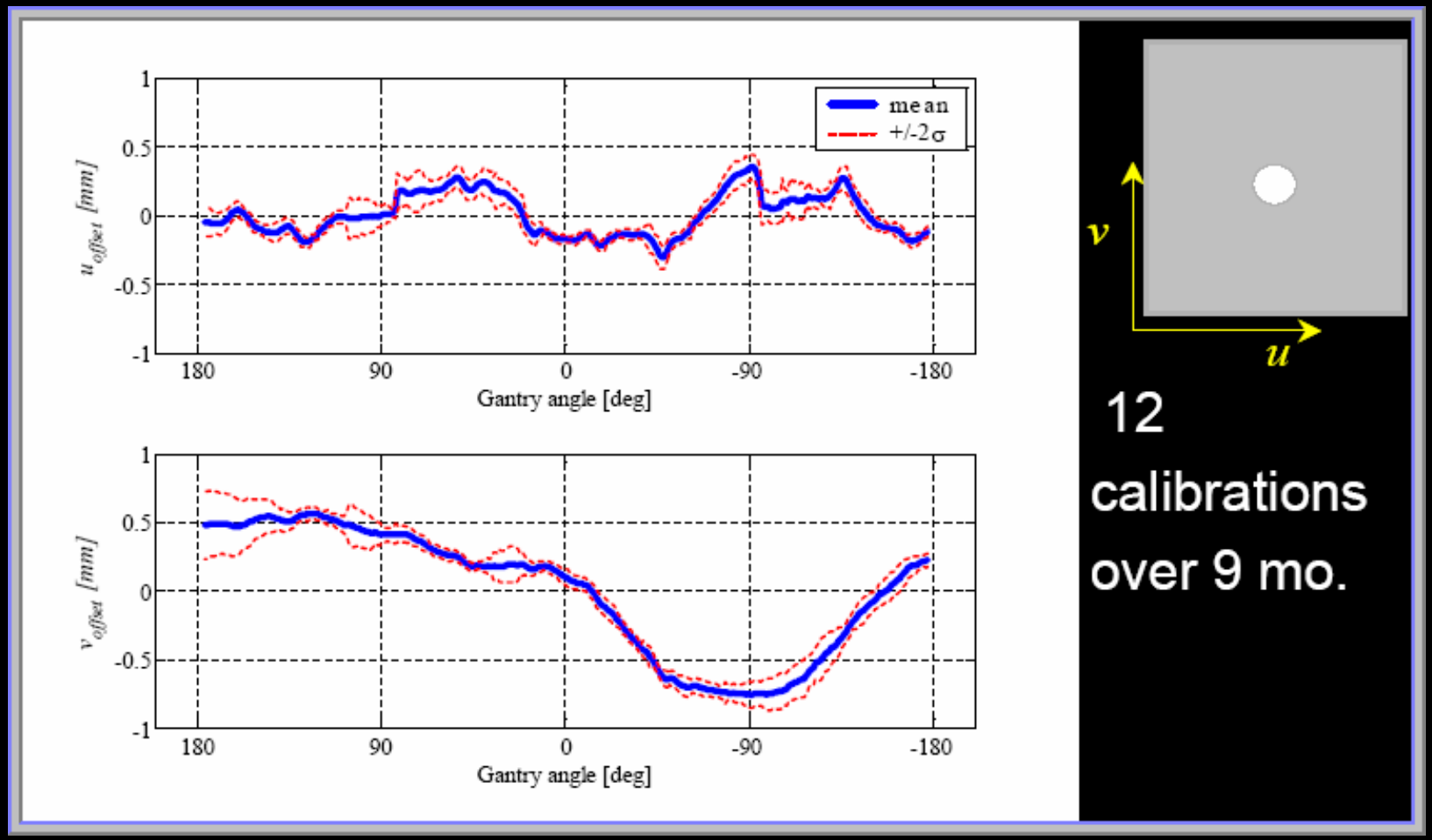
- MV images of a ball bearing are acquired at 4 gantry angles
- Adjust BB to MV isocenter
- KV images of BB are acquired (for 360^0 gantry angles)
- KV "Flex Map" generated / stored
- Apply "Flex Map" table for CBCT

❖ KV/MV Isocenter: essential for CBCT imaging





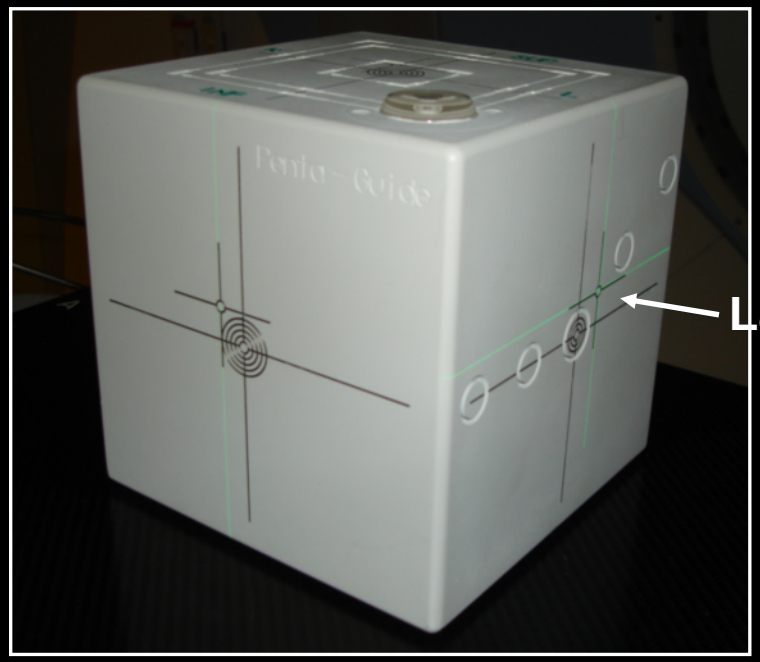
Long Term Stability: FlexMap



Sharpe *et al*, Med Phys 33(1), 2006

Daily “End-to-End” QA for CBCT

- KV/MV coincidence
- Setup parameters:
  isocenter, lasers…etc
- Automatic image registration accuracy (< 2 mm & 1 deg)
- Automatic couch shifts accuracy (< 2 mm)



Penta Guide Phantom

Image Registration (RCT/CBCT)

- Automatic Registration
  - Bone
  - Grey value
- Manual Registration

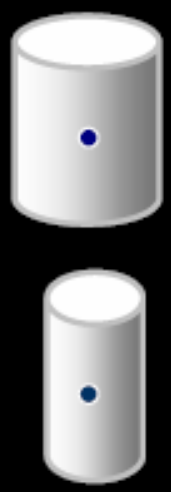
KV CBCT Patient Dose

Patient dose depends on

- Beam quality: HVL (KVp, filtration)
- Tube output: Reference (mR / mAs)
- Scanning geometry: SAD, FOV, # of projection
- Technique setting: mAs
- Patient size (Head, Pelvis…)

CBCT Dose at Isocenter

Dose in cGy/ 640 mAs; *FOV_x= 26 cm*



Phantom Size: dia.	FOV_z	100 kVp	120 kVp
30 cm	10 cm	0.58	1.07
	26 cm	0.80	1.5
16 cm	10 cm	1.52	2.68
	26 cm	1.9	3.2

D. Jaffray - PMH

CBCT Dose in Rando® Phantom

(For 125 KVp, 80 mA, 25 ms – Varian standard settings)*
Total 26 organs measured

H/N:	(Dose in cGy)
❖ Skin (irradiated site) :	6.7 ± 1.2
❖ Bone marrow (is) :	5.9 ± 0.8
❖ Thyroid :	11.1 ± 1.2
❖ Esophagus :	3.8 ± 4.4
❖ Spinal cord :	4.1 ± 3.6
❖ Lens :	6.2 ± 0.5
❖ Thymus :	11.1 ± 1.2
Effective dose :	10.3 ± 0.5 mSv

* 1320 mAs (660 projections, 2 mAs per projection). 330 proj. typically for Elekta

Kan *et al* (2008), IJROBP, 70(1), 272-279

(CBCT dose for 125 KVp, 80 mA, 25 ms)

Chest:	(Dose in cGy)
❖ Skin (irradiated site) :	6.4 ± 1.0
❖ Bone marrow (is) :	6.9 ± 0.5
❖ Breast :	4.7 ± 0.2
❖ Esophagus :	3.6 ± 2.6
❖ Spinal cord :	3.6 ± 3.2
❖ Heart :	6.7 ± 0.6
Effective dose :	23.6 ± 0.4 mSv

Kan *et al* (2008), IJROBP, 70(1), 272-279

(CBCT dose for 125 KVp, 80 mA, 25 ms)

Pelvis:	(Dose in cGy)
❖ Skin (irradiated site) :	5.4 ± 1.4
❖ Bone marrow (is) :	4.2 ± 0.3
❖ Bladder :	5.3 ± 0.9
❖ Rectum :	4.0 ± 0.3
❖ Small intestine :	6.3 ± 0.3
Effective dose :	22.7 ± 0.3 mSv

Daily CBCT potentially increase secondary cancer risk by up to 2 – 4% (based on probability of 5 x 10^{-5} per mSv – ICRP 60)

Reduced mAs setting (40 mA, 10 ms) reduces doses to 1/5th

Kan *et al* (2008), IJROBP, 70(1), 272-279

CBCT Data Transfer - Xio to XVI

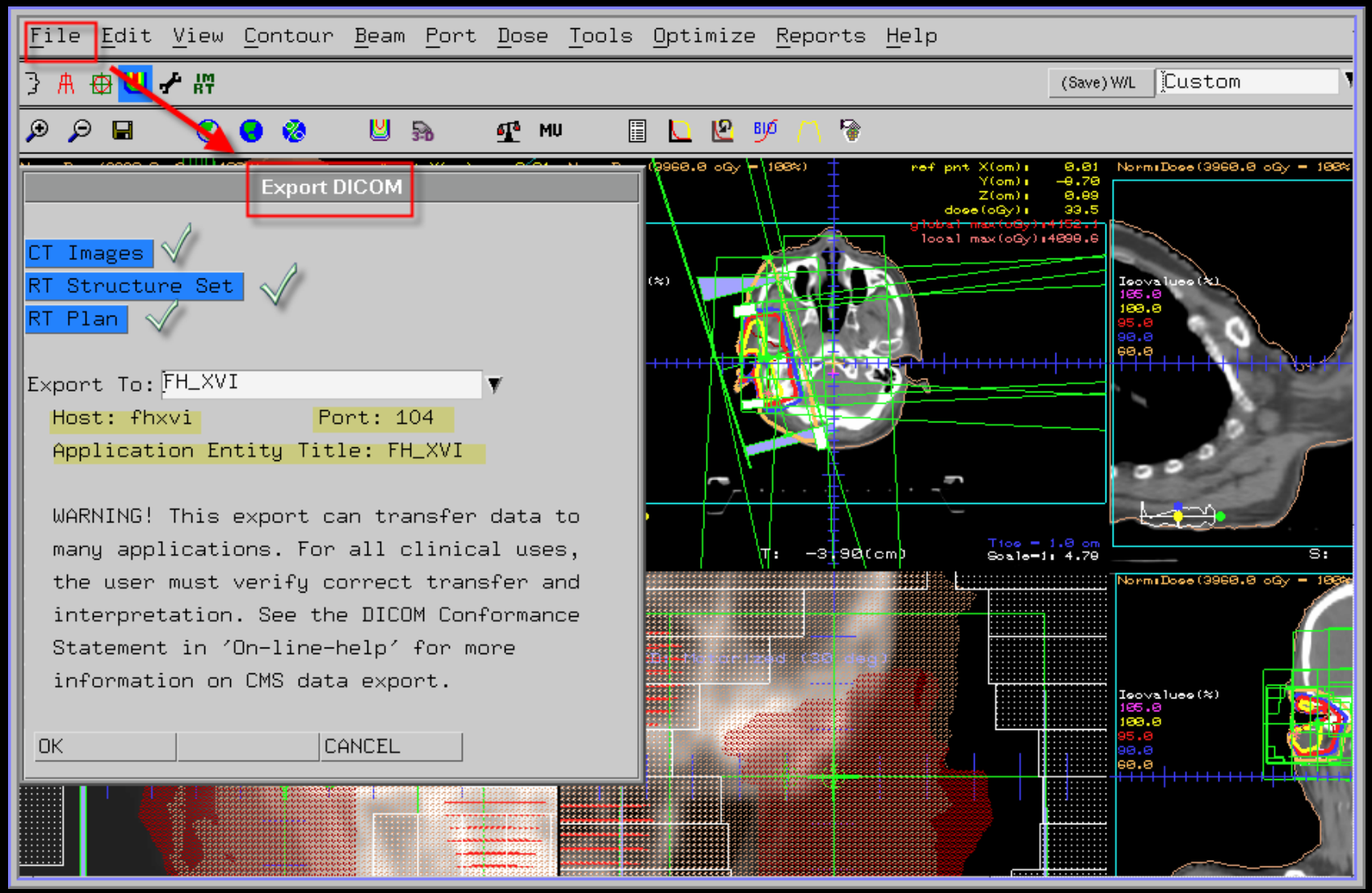
Need DICOM export setup

- Port number
- Application Entity Title
- Host Name … etc

3D Reference data required for CBCT

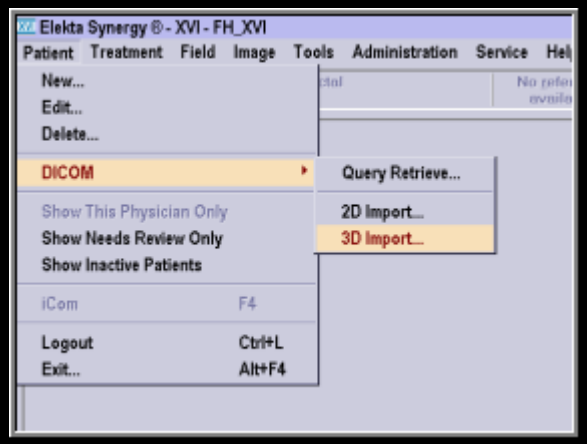
- RT plan
- Structure contours
- CT data

CBCT Data Transfer - Xio to XVI

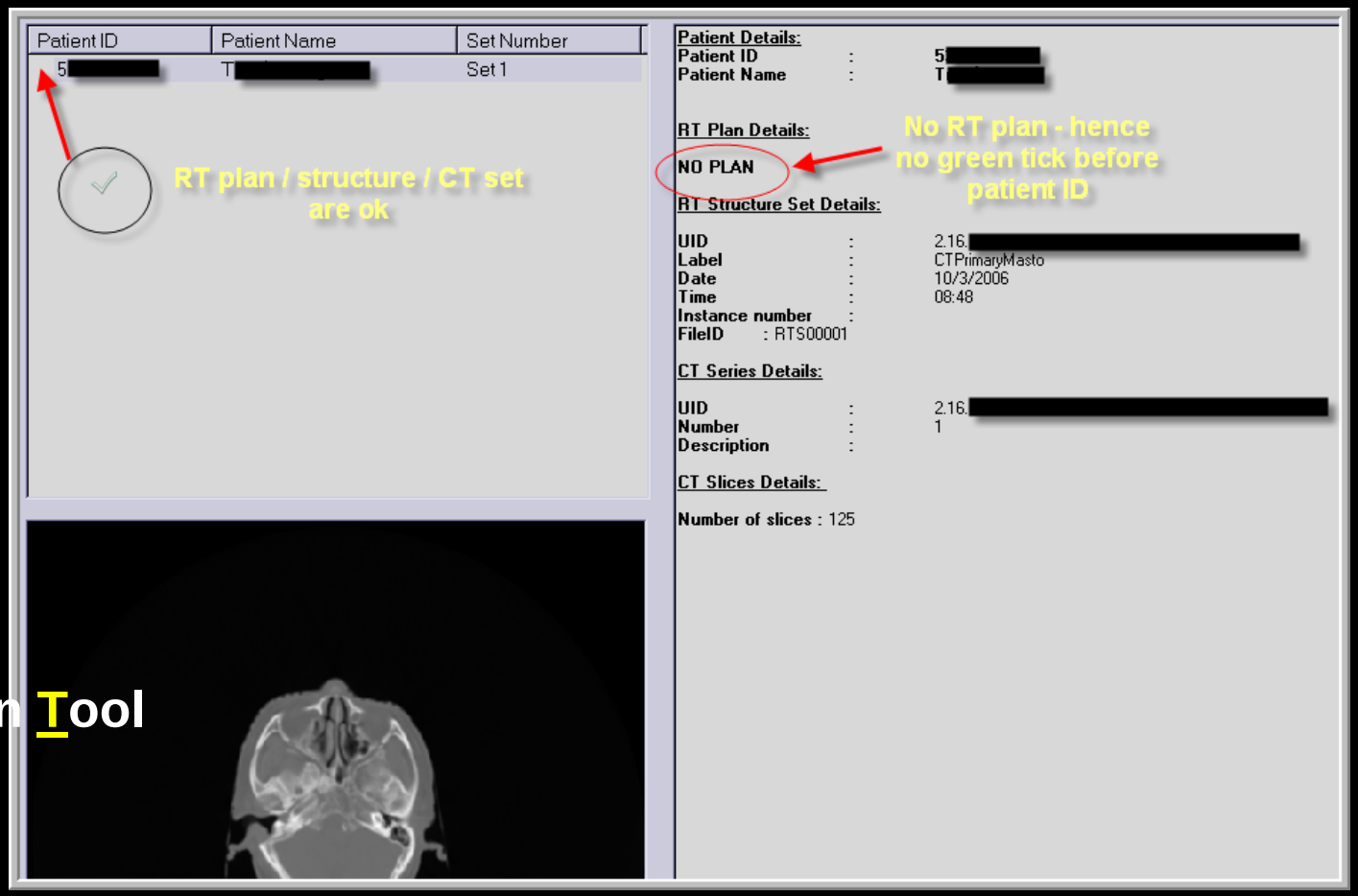


Importing 3D Reference Data from the DIVT

(in XVI)



DICOM 3D Import

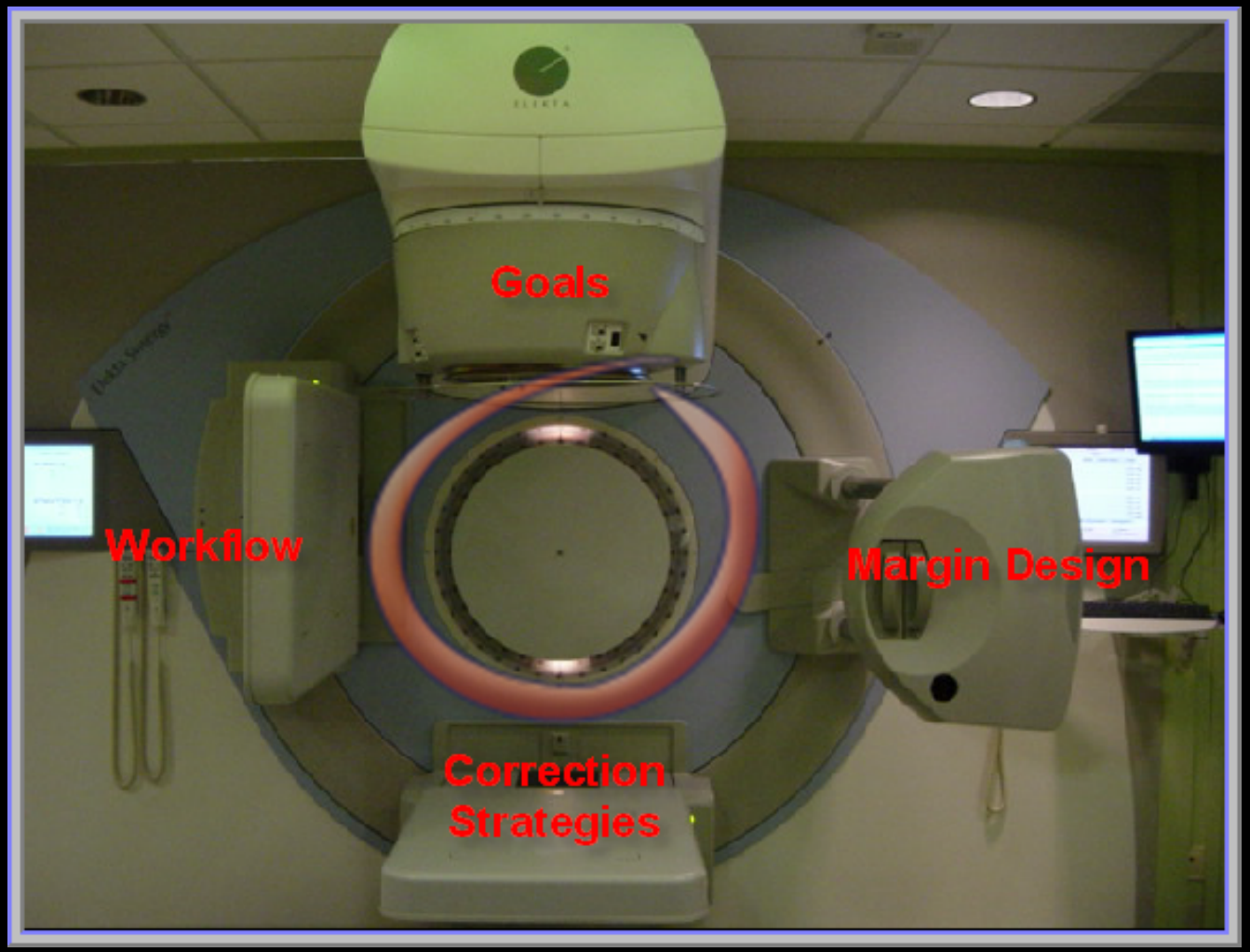


DICOM Import Validation Tool

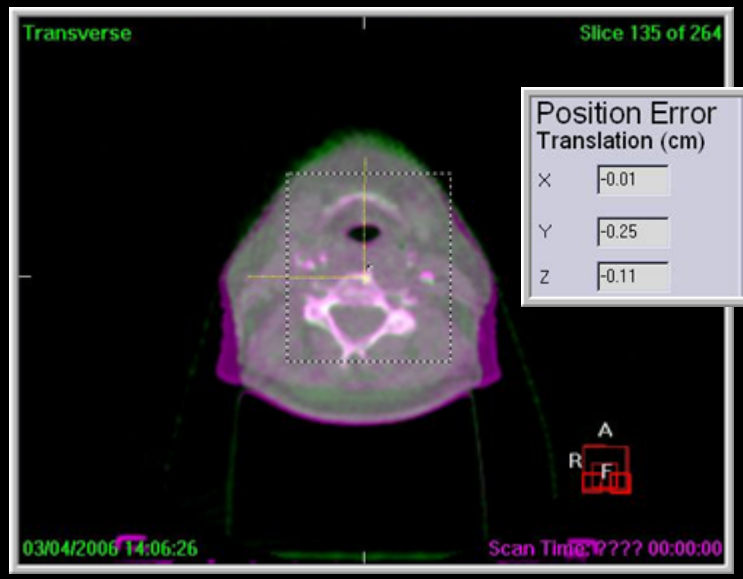
Cautions in Reference Data Import

- **Correctly associate reference images and plan data with the correct treatment site ?**
  - Check the imported data are correct
  - Check the RT plan
  - Wrong plan (wrong isocenter in particular) could result in wrong treatment correction
- **Optimize image registration and verify**
  - Define appropriate alignment clipbox for image registration (“Bone” or “Grey value” registration)
  - Need to verify the registration quality

IGRT Clinical Application



IMRT H/N 70/63/56 Gy in 35 fx



Position Error	Translation (cm)	Rotation (dg)
X	-0.01	359.0
Y	-0.25	0.4
Z	-0.11	359.0

Shift caused by patient wearing a thick sweater

Table Correction	(cm)
Lateral	0.02
Longitudinal	0.25
Vertical	0.09

Rectum

50.4 Gy in 28 fx
3 Flds

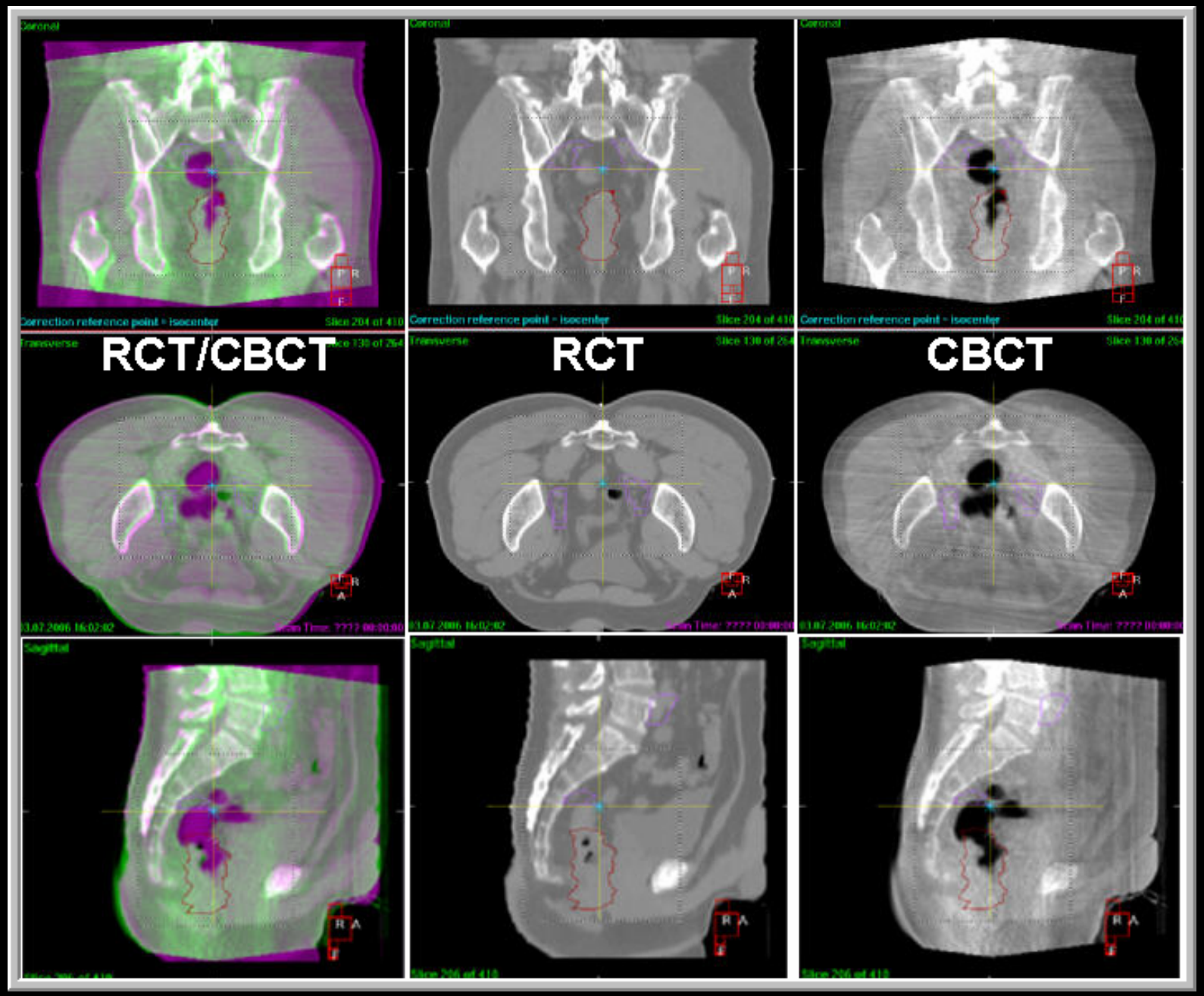


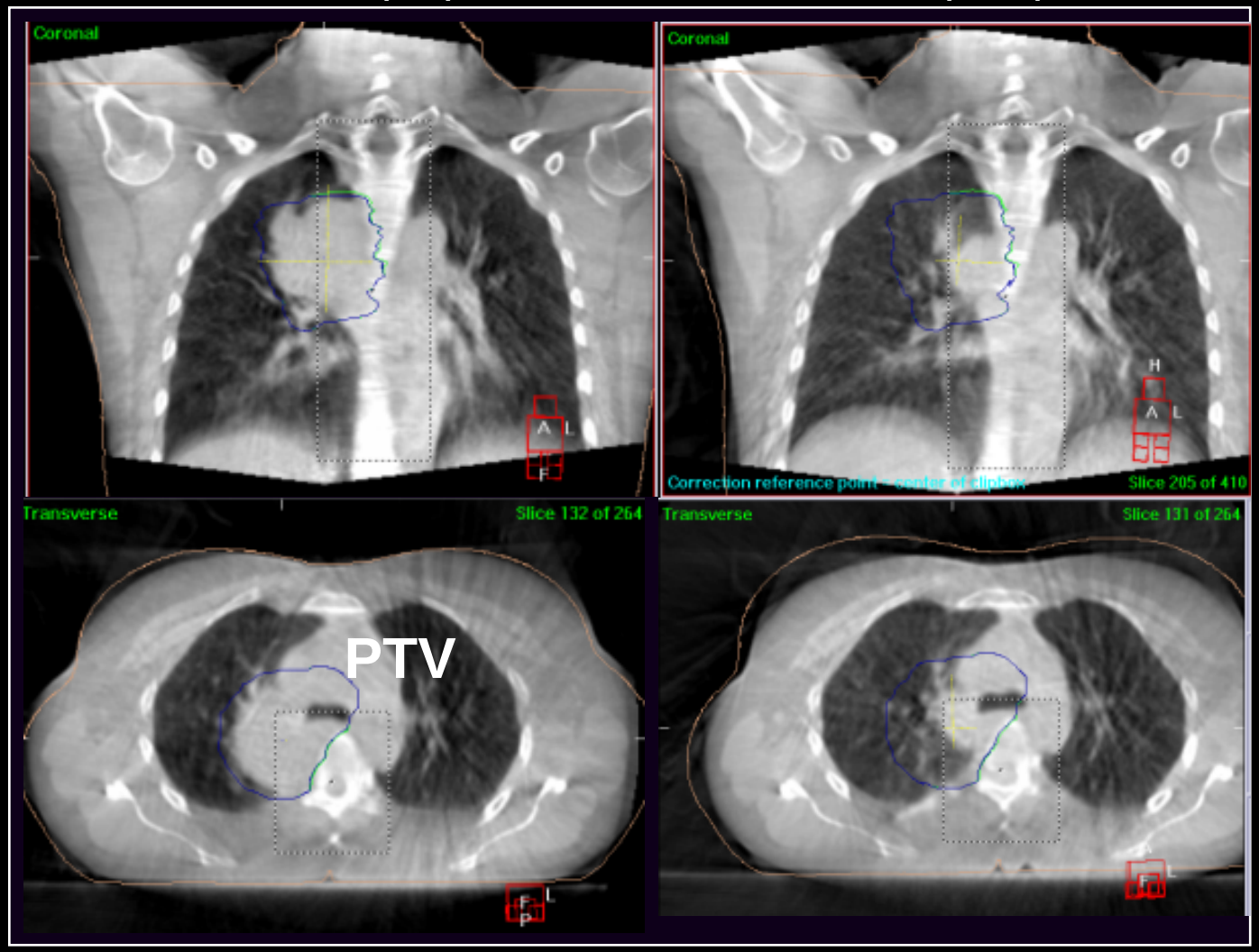
Table Correction
(base on bone)

Lat:	-0.13 cm
Long:	-0.24 cm
Vert:	-0.13 cm

NSCLC

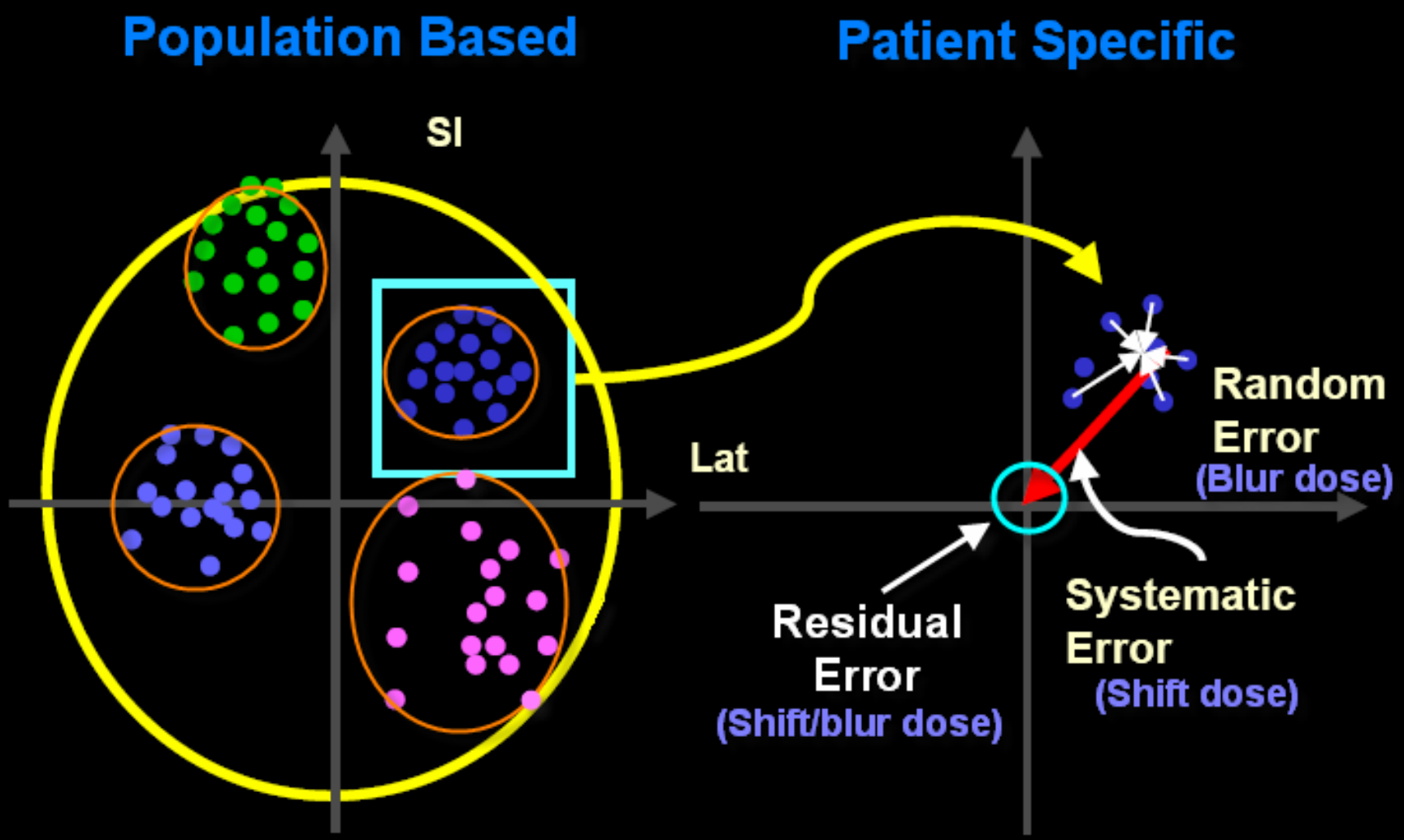
3DRT (64.8 Gy)
+ Chemo

CBCT (1F) CBCT (25F)



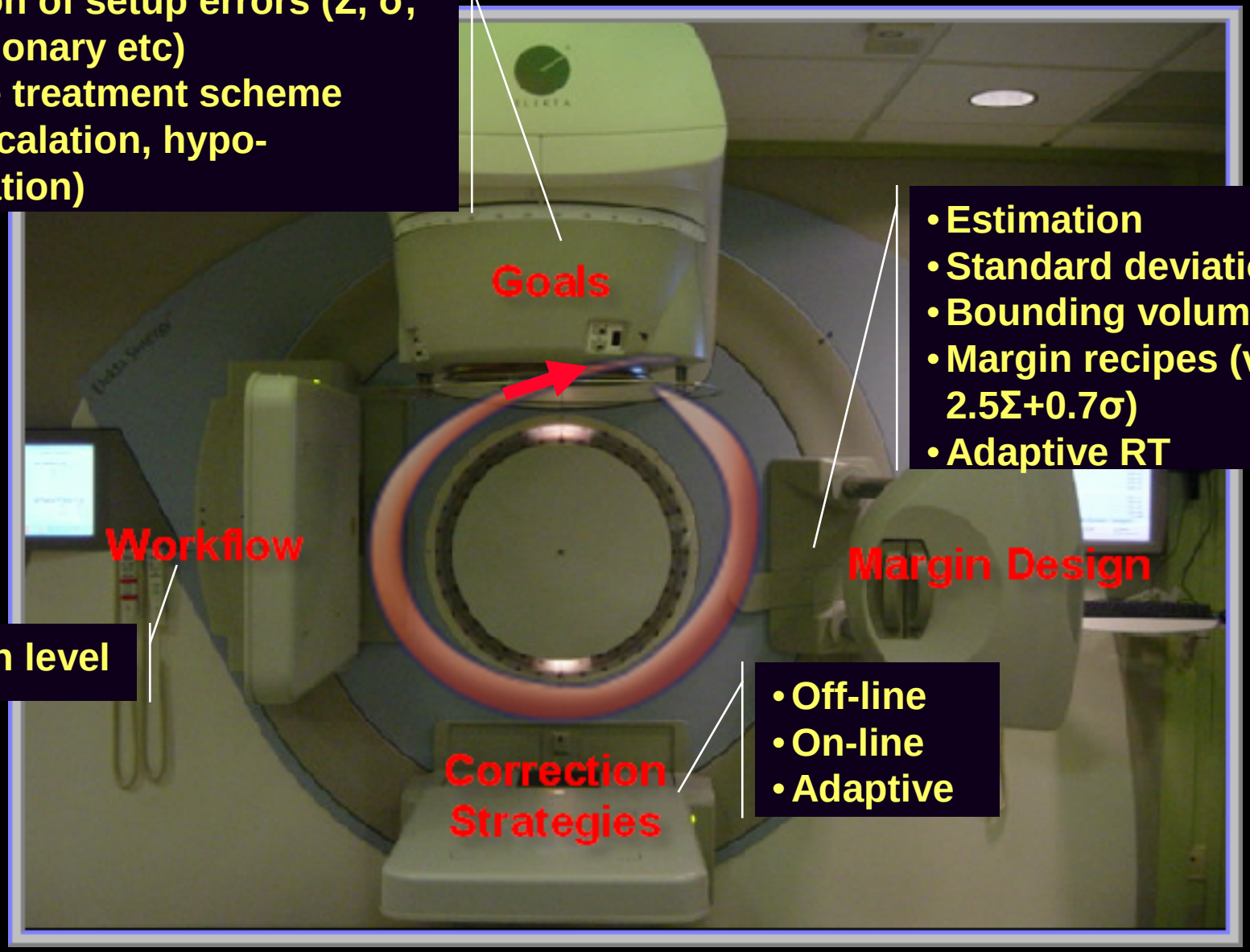
Change in target volume after 45 Gy

Geometric Uncertainties



IGRT Clinical Application

- Reduction of setup errors (Σ, σ, non-stationary etc)
- Optimize treatment scheme (dose escalation, hypo-fractionation)



- Estimation
- Standard deviation multiple
- Bounding volume
- Margin recipes (van Herk's 2.5Σ+0.7σ)
- Adaptive RT

Action level

- Off-line
- On-line
- Adaptive

Hybrid Off-line Correction Strategies

(Two Strategies – NAL and Running-Mean (RM))

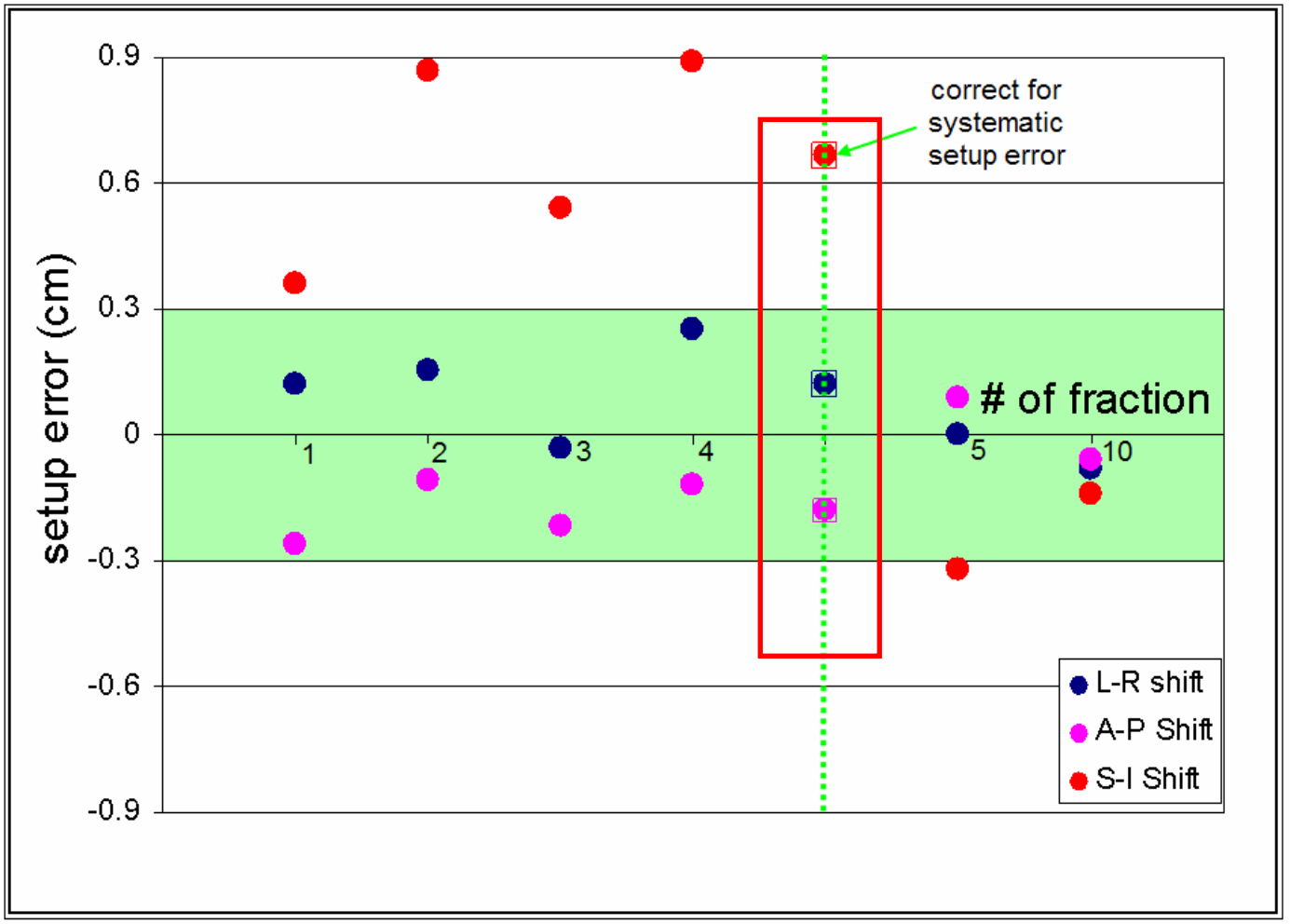
NAL: CBCT 1 – 4 Fx

Fraction Number		1	2	3	4	Systematic	Random	5	6
Imaging Method		CBCT	CBCT	CBCT	CBCT	Call Physics if random error exceeds 0.3 cm		CBCT	CBCT
Image Reg. Method									
1st CBCT									
Setup Error (cm)	X Shift (+/-)	0.12	0.15	-0.03	0.25	0.1	0.12	0	-0.08
	Y Shift (+/-)	-0.26	-0.11	-0.22	-0.12	-0.2	0.07	0.09	-0.06
	Z Shift (+/-)	0.36	0.87	0.54	0.89	0.7	0.26	-0.32	-0.14
Repeated Imaging? (Y/N)		Y	Y	Y	Y			n	N
2nd CBCT									
Residual Error (cm)	X Shift (+/-)	-0.03	-0.03	0.05	-0.02	0.0	0.04		
	Y Shift (+/-)	0.1	-0.01	0.05	-0.07	0.0	0.07		
	Z Shift (+/-)	0.05	0.07	0.04	0.05	0.1	0.01		

RM: CBCT 1- 4, 5, 10…Fx

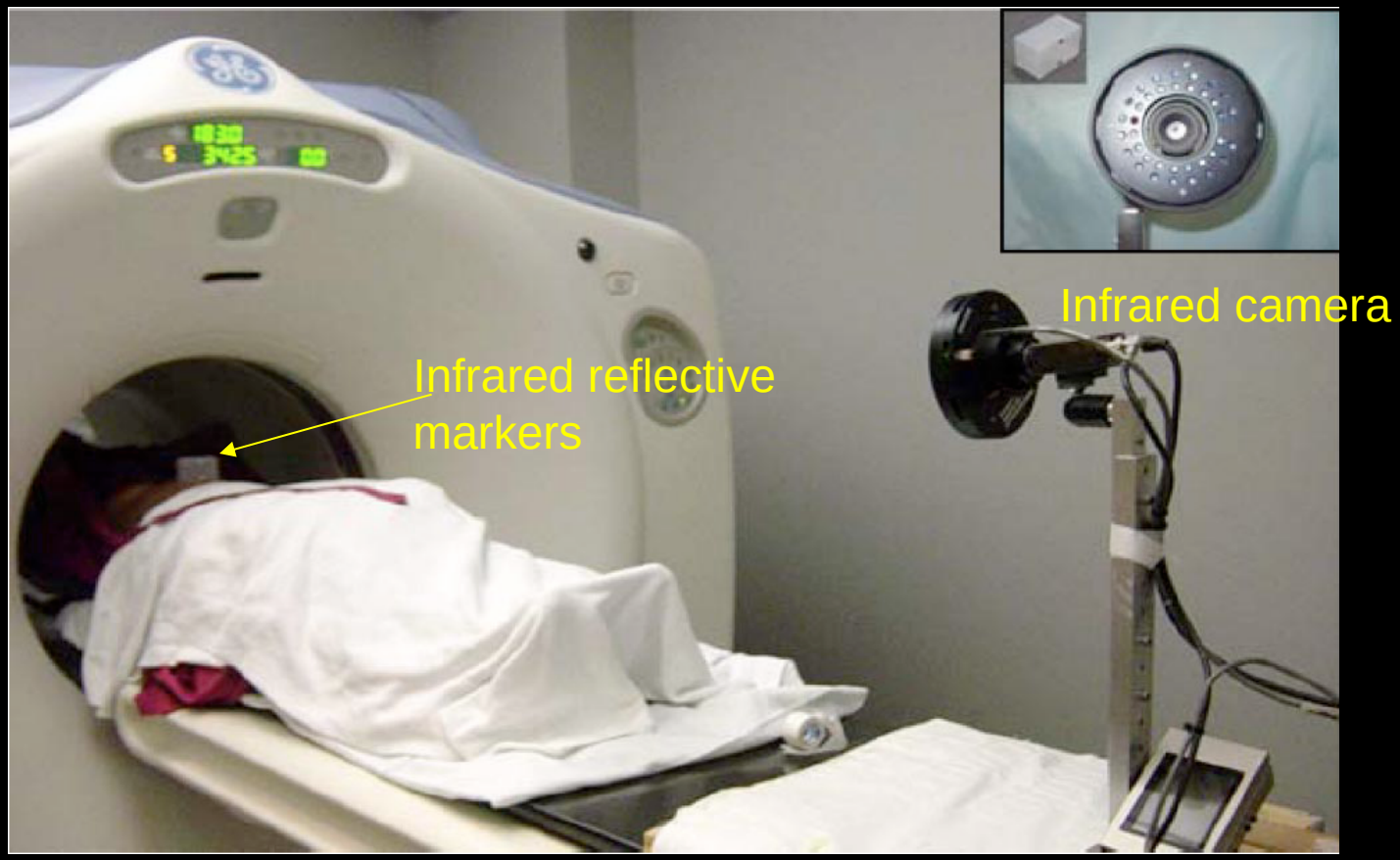
Data from 4 Consecutive CBCTs are Analyzed.
Systematic Error Identified, and Corrections Implemented.
Action Level is typically 3 mm.

Running-Mean Strategy



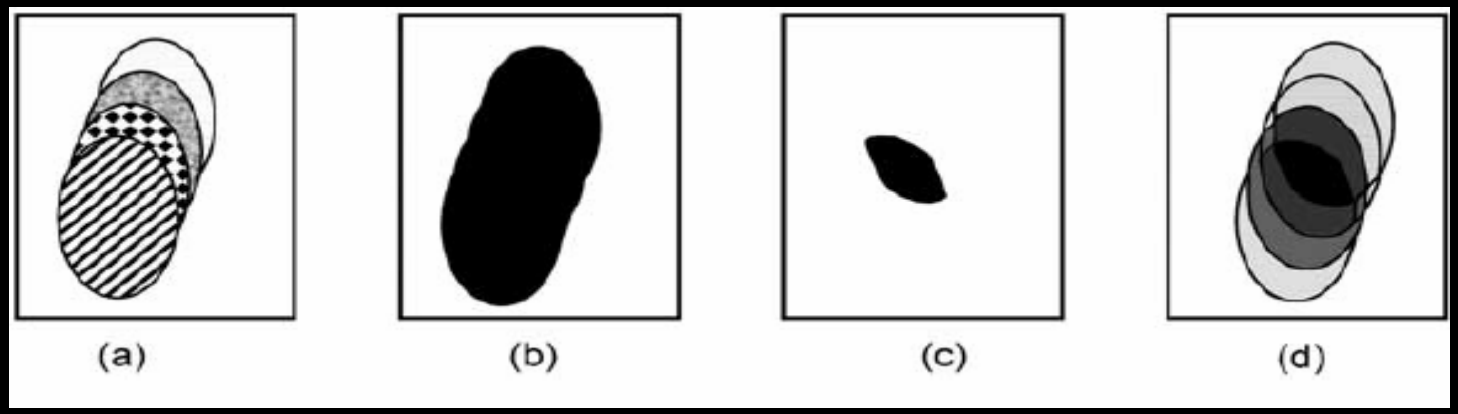
"equivalent" to NAL in this case

Motion-encompassing Treatment Strategy for Lung



Start with treatment planning using 4D-CT

Reconstructed Images from 4D-CT



Underberg, et al, IJROBP, 63(1)253-260, 2005.

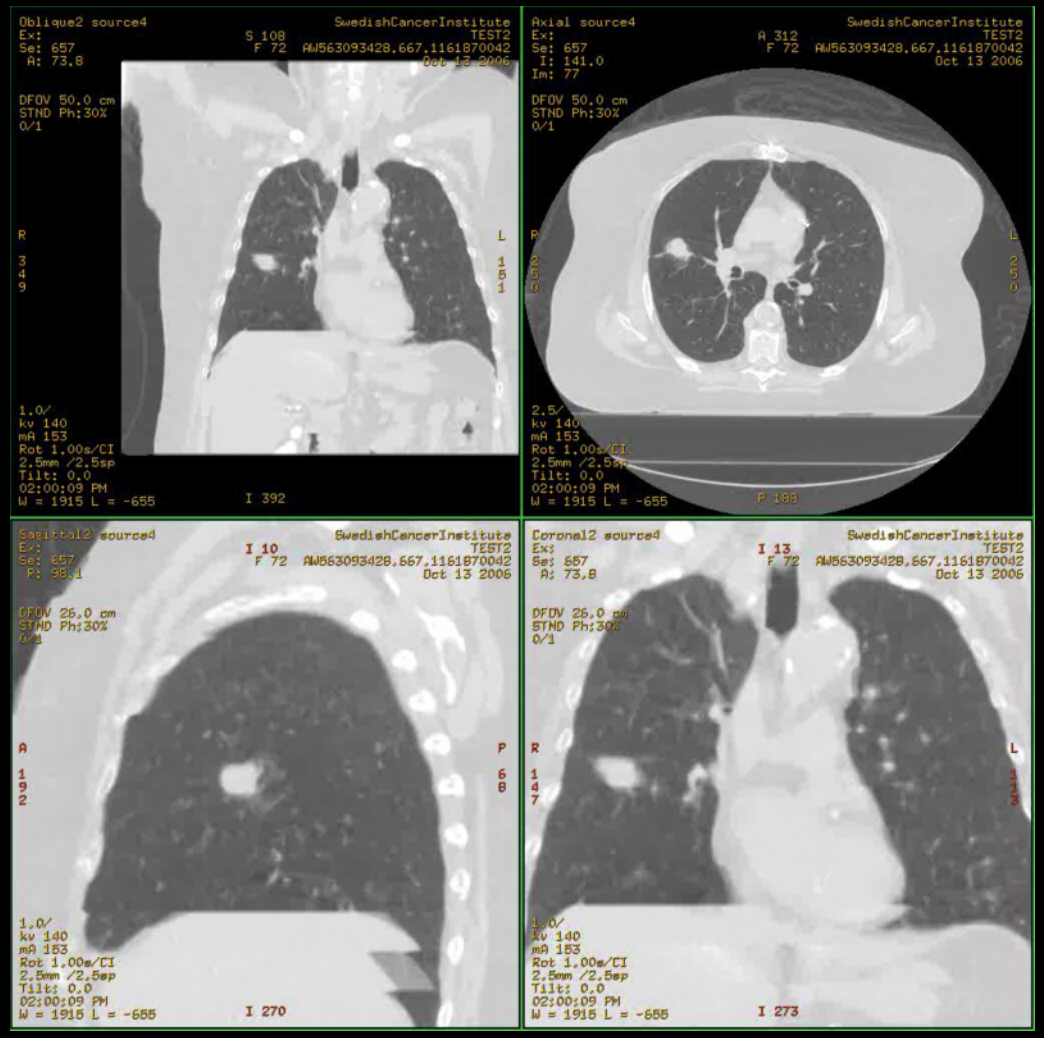
A) Separate phases of tumor during respiration
B) Maximum intensity projection (MiP)
C) Minimum intensity projection (Min-iP)
D) Average intensity projection (Ave-iP)

4D-CT for Internal Target Volume

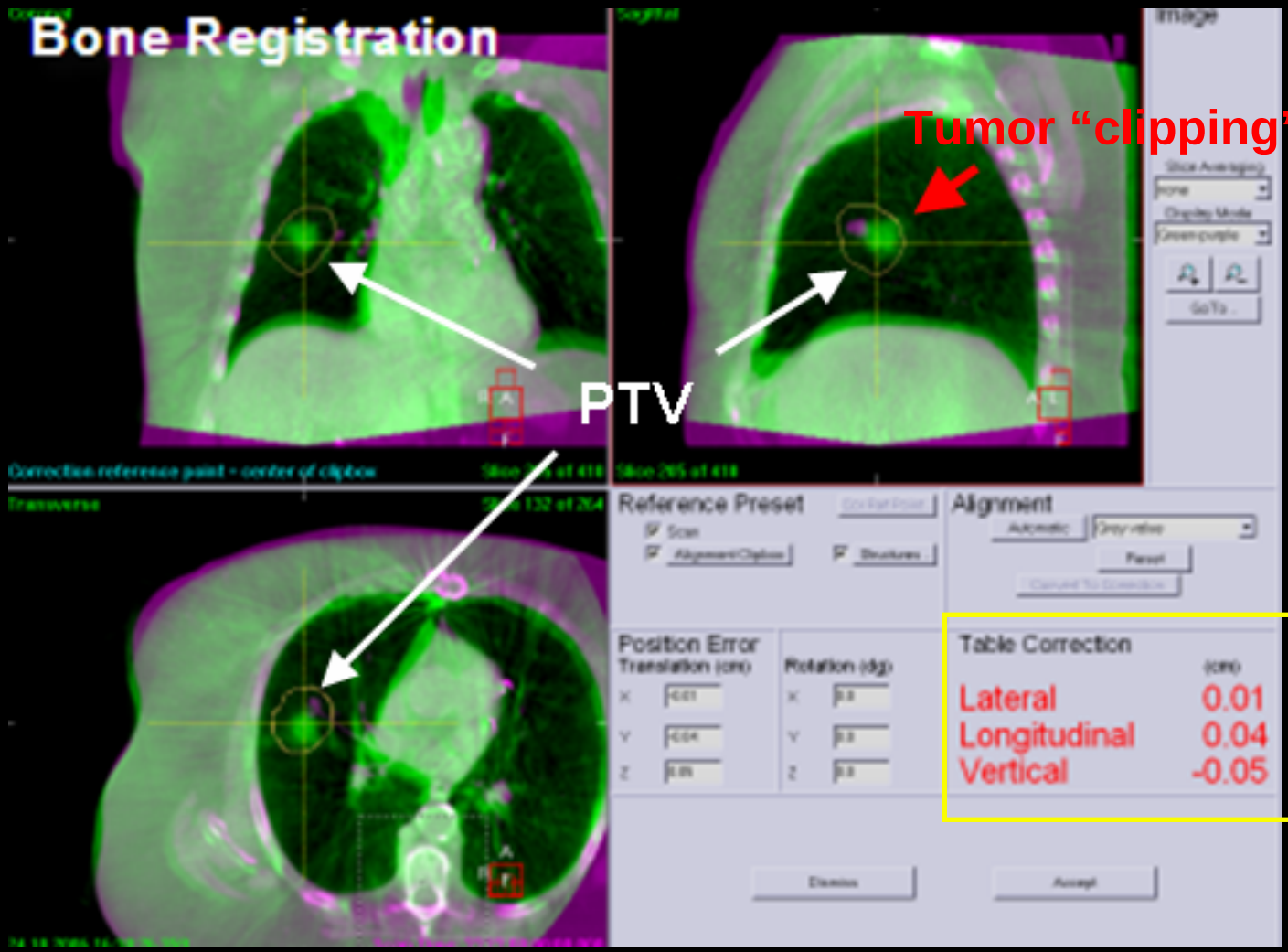
Use MiP for ITV delineation

5 mm expansion for PTV

Ave-iP for dose calculation

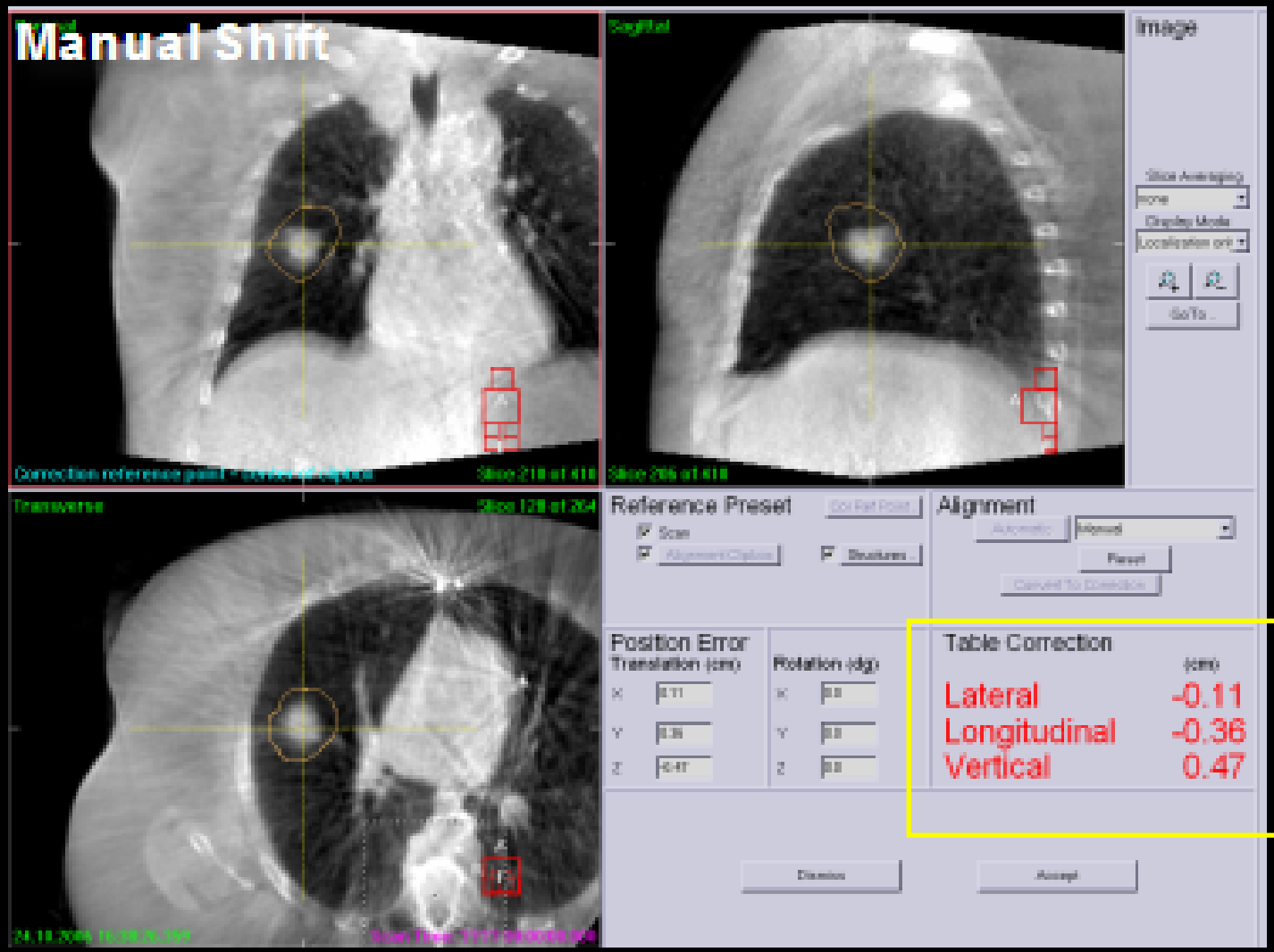


CBCT for setup verification



Setup correction based on bone registration

Additional “manual” shift to improve precision



New setup correction

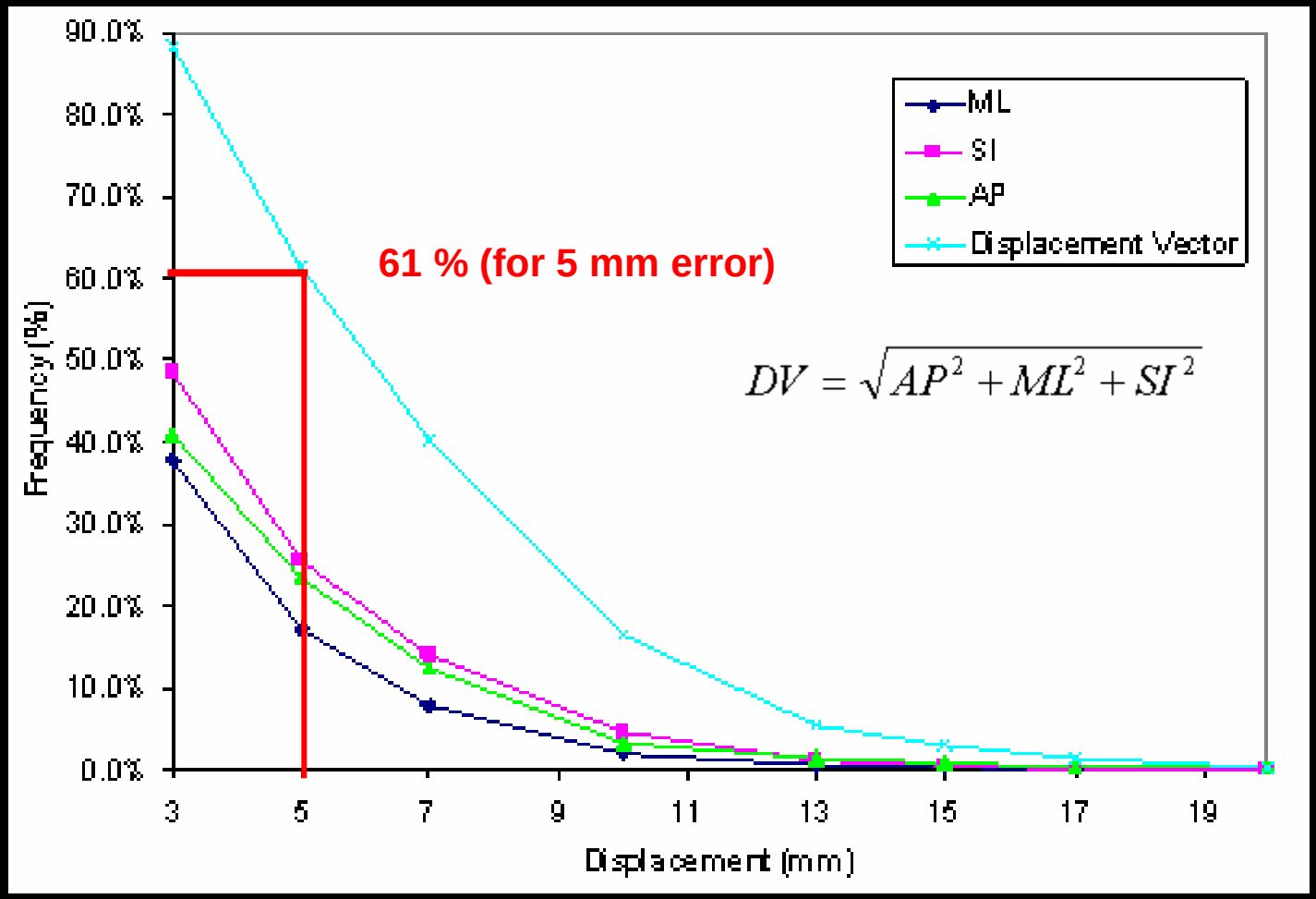
Set-up Errors for Lung

- 22 NSCLC patients had daily CBCT IGRT
- Setup shifted when errors exceeded 3 mm
- Systematic & random errors and 3D displacement vector (DV) were analyzed retrospectively

DV = 9.9 ± 4.7 mm

Direction	Errors (mm)
AP	5.2 ± 3.2
ML	4.4 ± 2.7
SI	4.4 ± 3.4

Residual Setup Errors for Lung (NAL Strategy)



References

- Sharpe *et al*, Med Phys, 33(1): 136-144, 2006
- Lehmann *et al*, JACMP, 8(3): 21-36, 2007
- Yoo *et al*, Med Phys, 33(11): 4431-4447, 2006
- Underberg *et al*, IJROBP, 63(1): 253-260, 2005
- Rietzel *et al*, IJROBP, 61(5): 1535-1550, 2005
- Kan *et al*, IJROBP, 70(1): 272-279, 2008
- Grills *et al*, IJROBP, 70(4): 1045-1056, 2008

Thank you for your attention