kV-& MV-CBCT Imaging for Daily Localization: Commissioning, QA, Clinical Use, & Limitations

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Questions

- Disease Stage (local, regional, metastatic)
- Tumor location
- Edge of the tumor volume
- Nodes involvement
- Tumor within Rx fields
  - Respiratory Motion
- OARs location
- Modulate the intensity to maximize the therapeutic ratio

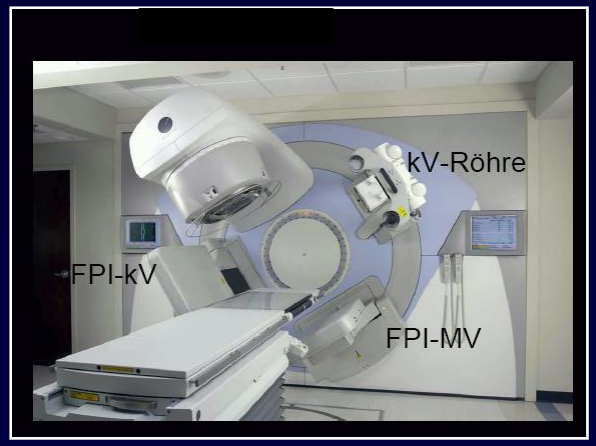
In-Room Imaging Technologies

CT on rails

2D kV Imaging

kV CB Imaging

kV & MV CB Imaging



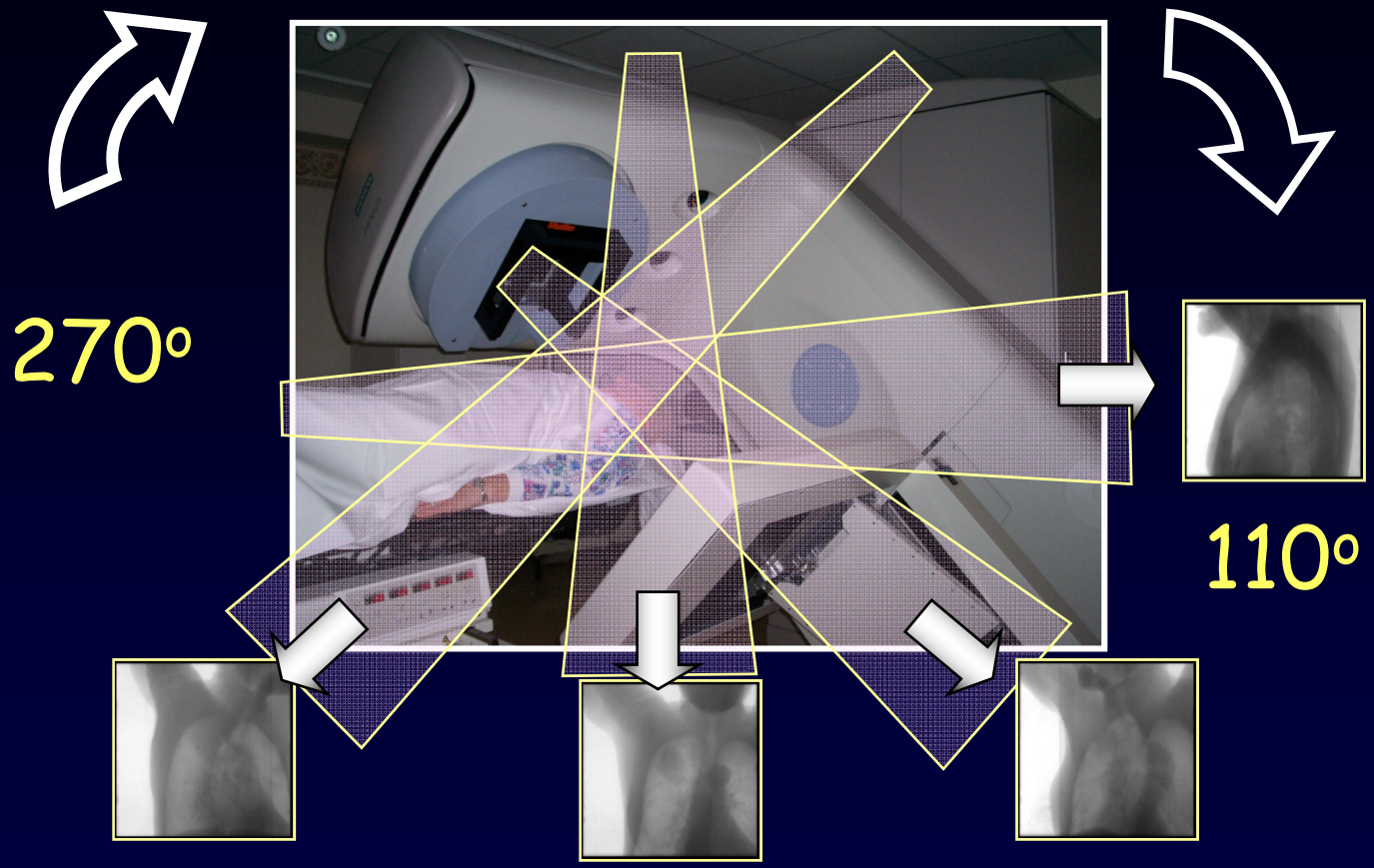
kV CB Imaging

MV-CT Imaging

Mega-Voltage CBCT

- MV-CBCT features & characteristics
- The image quality vs. exposure challenge…
- … and an elegant workaround
- MV-CBCT as a localization system
- Thinking outside the box
- QA
- Clinical experience
- Conclusions

MV-CBCT Basics

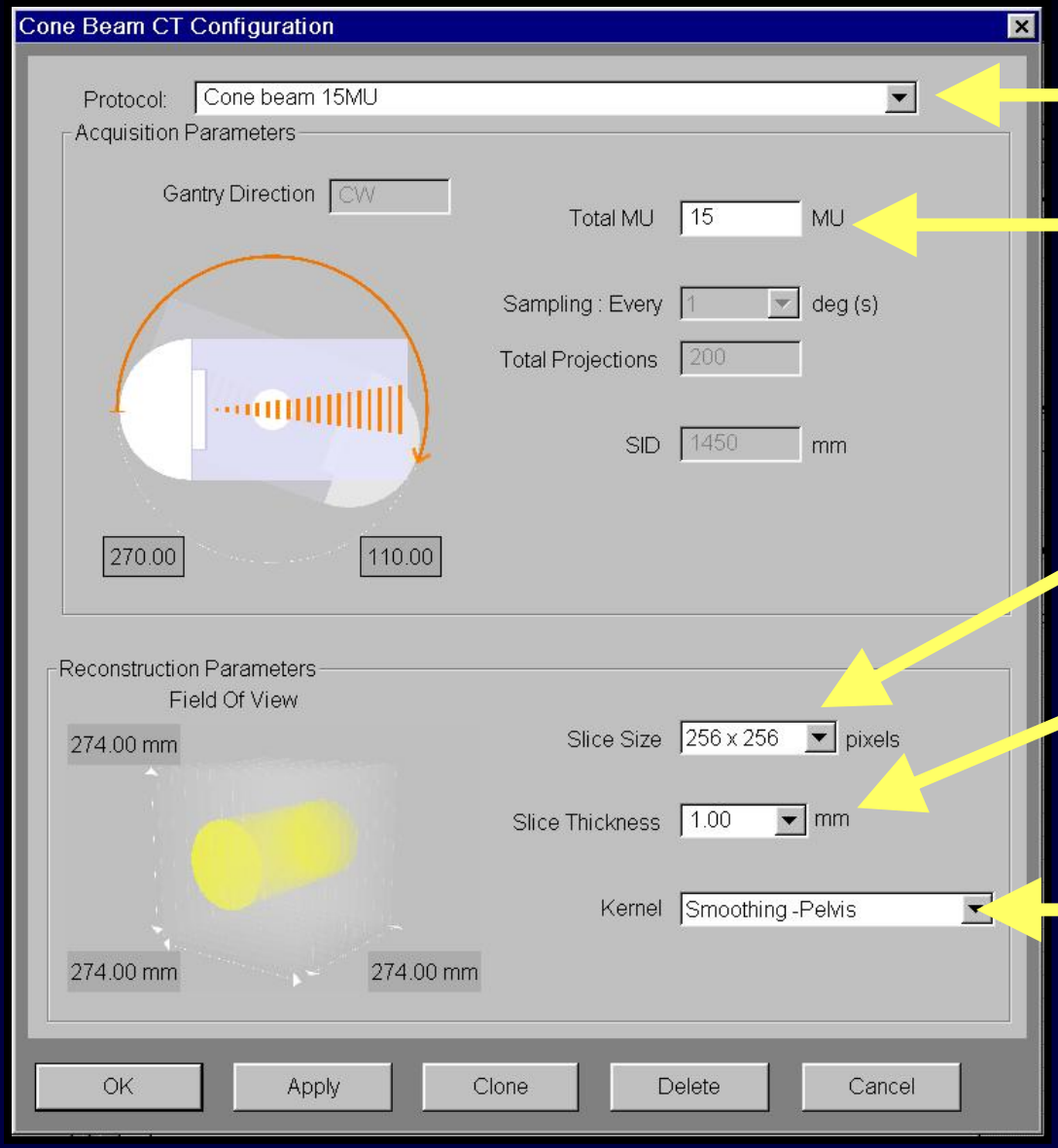


3, 5, 8, 10, 12, & 15 MU delivery protocols
(0.01-0.1 MU per projection)

Features of MV-CBCT

- Volumetric patient image using a 6x beam
- High sensitivity a-Si panel
- Synchronization of beam pulse & panel read out
- Gantry rotation of 200 degrees
- Time: acquisition ~ 50 sec & recon. ~ 1 min
- 27 cm^3 max FOV (FS 27.4 x 27.4 cm & SID @ 145 cm)
- Slice thickness range: 1 mm to 5 mm
- CT image sizes: 128^2, 256^2 or 512^2 pixels
- Dose delivered 3 cGy – 12 cGy

MV-CBCT Configuration



CB Protocol Name

MUs (1-200)
4, 10, 15 MU

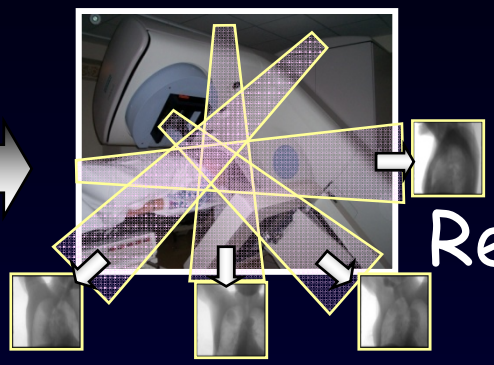
Slice Size: 128x128, 256x256, 512x512

Slice Thickness
0.5 to 10 mm

Reconstructing Kernel:
Smoothing,
Smoothing H&N,
Smoothing pelvis

MV-CBCT Localization

Acquisition



Reconstruction

Registration

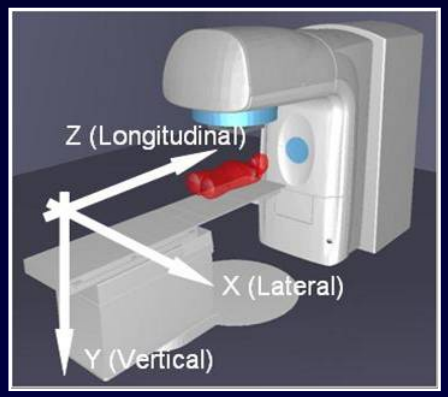
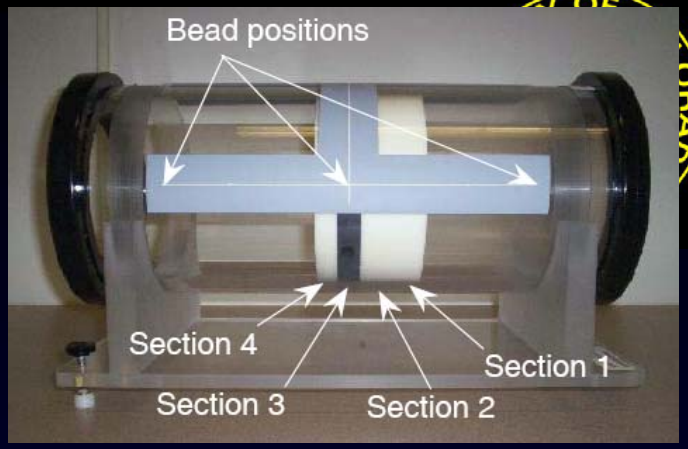


Table offsets

4-6 minutes

An Integrated System

Image Contrast vs. Exposure



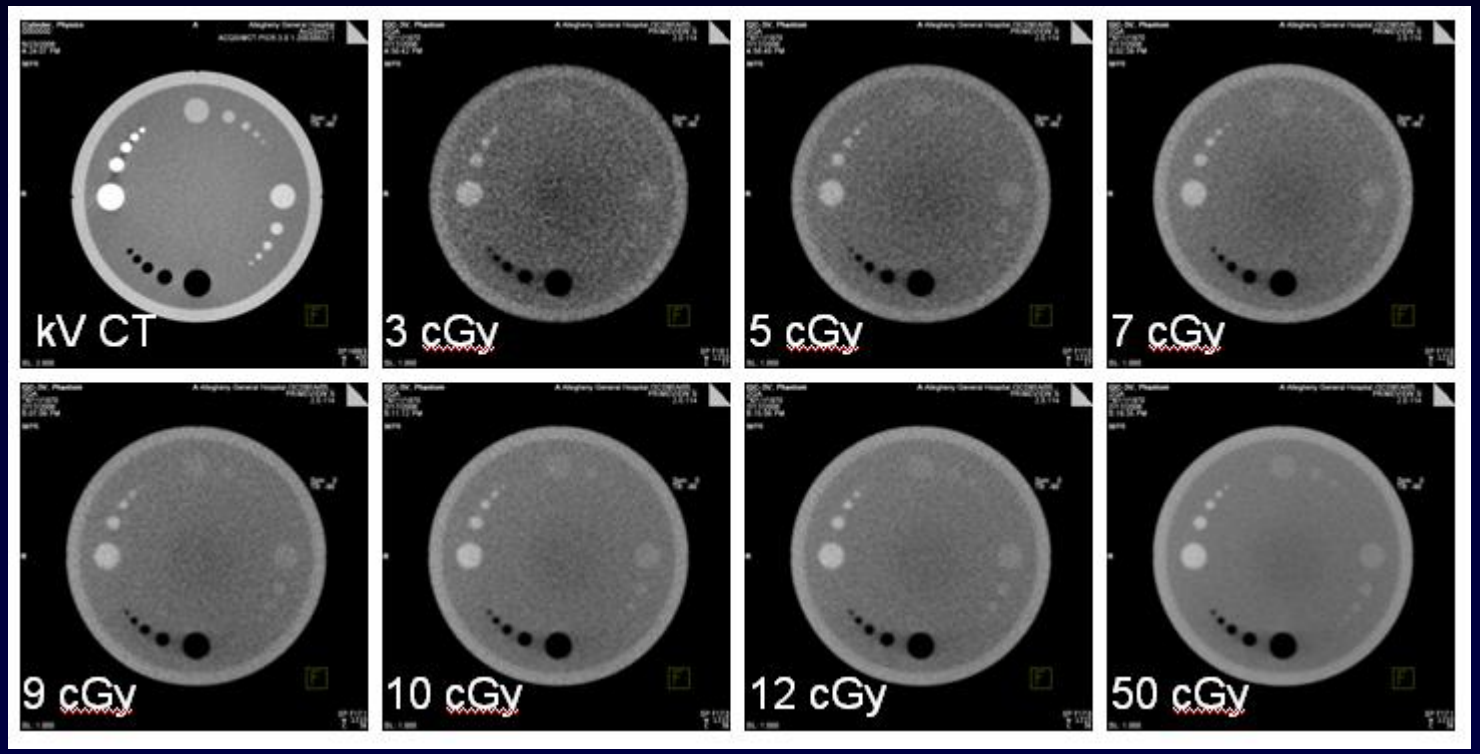
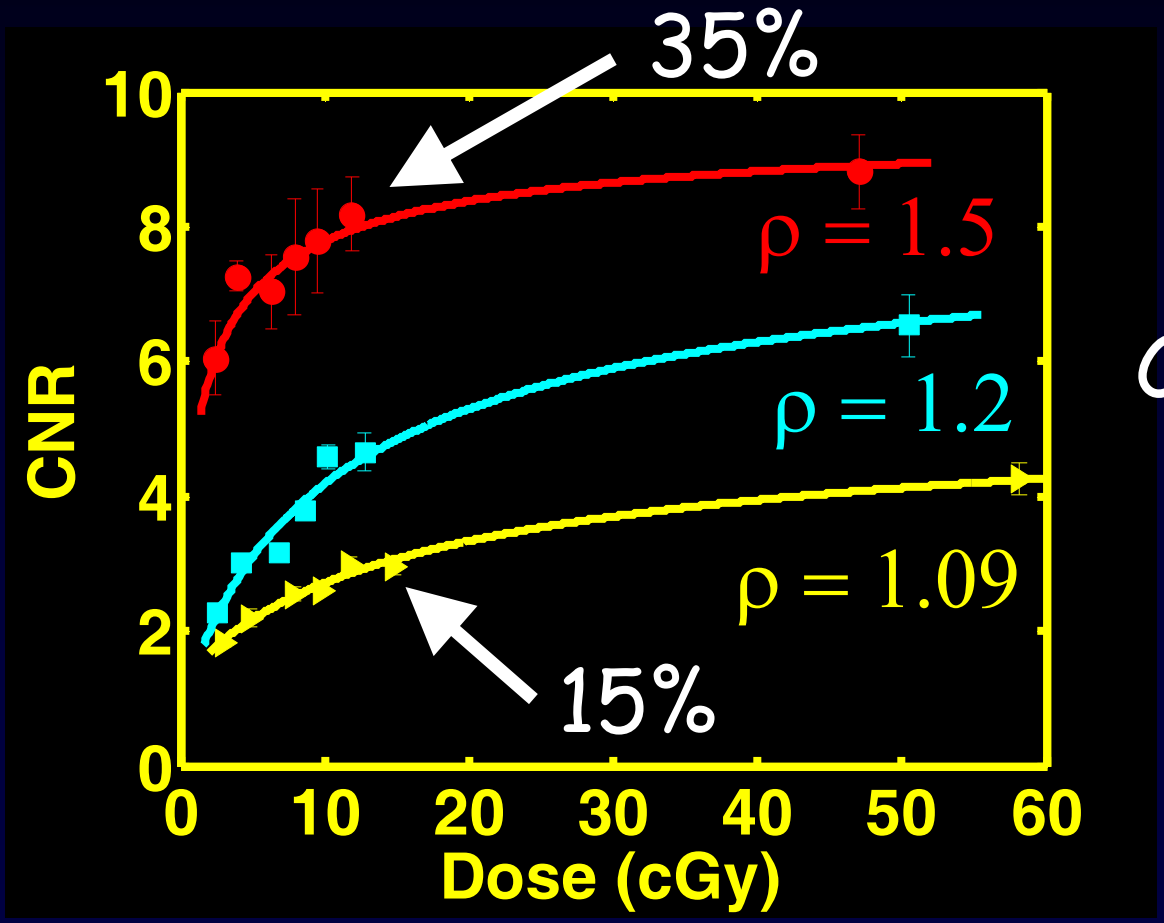


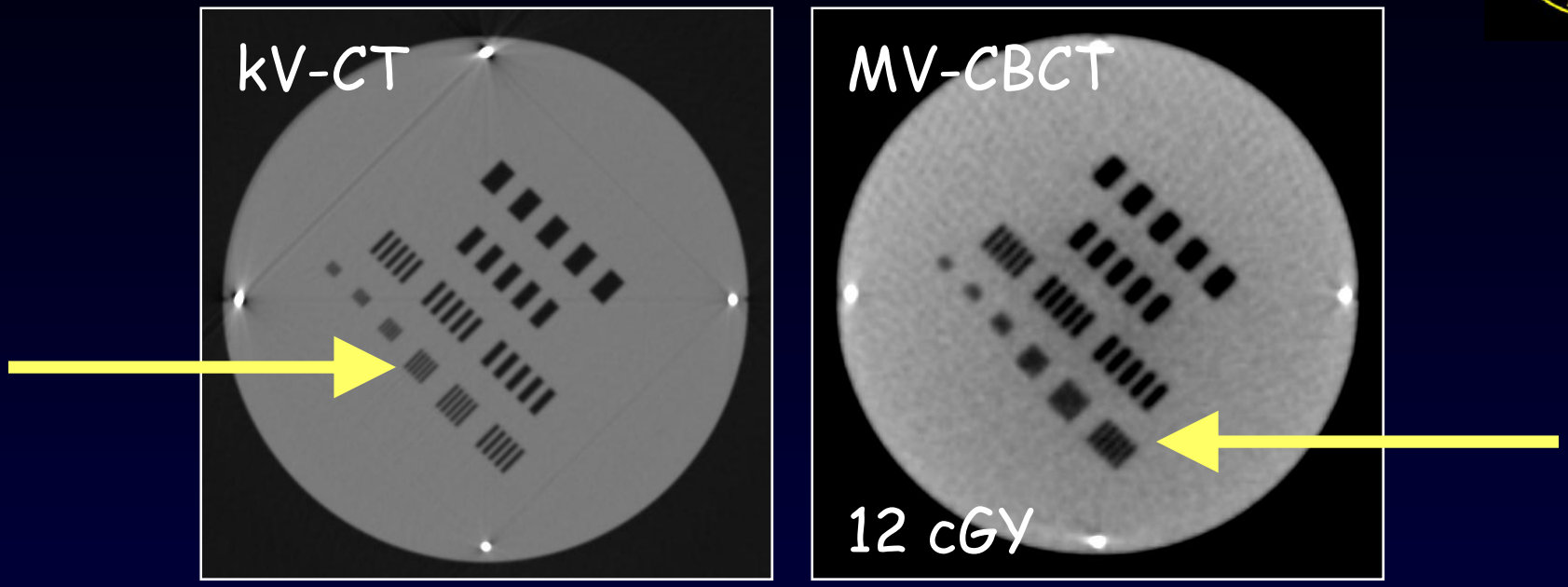
Image Quality Phantom

CNR vs. Dose for 7 MU Protocols and 3 Materials



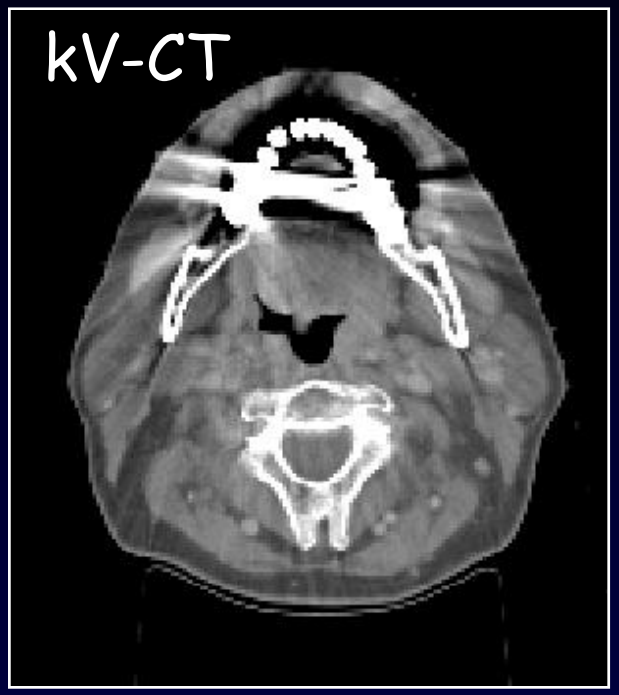
CNR ~ √dose

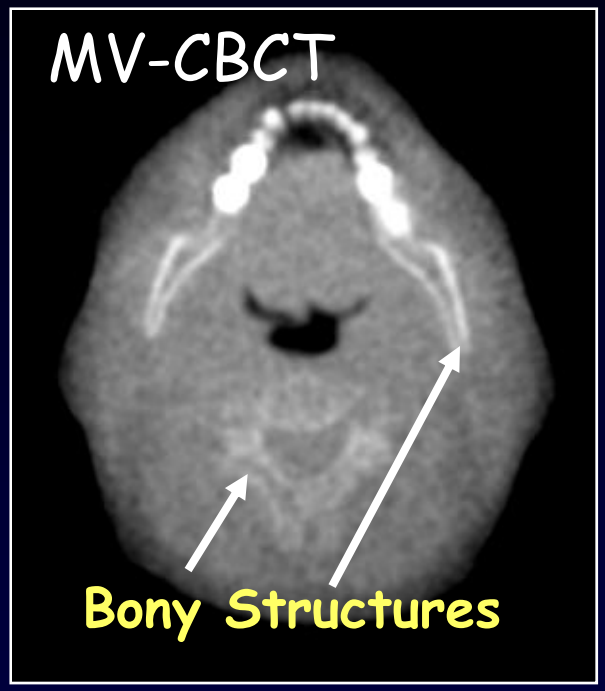
Resolution vs. Exposure

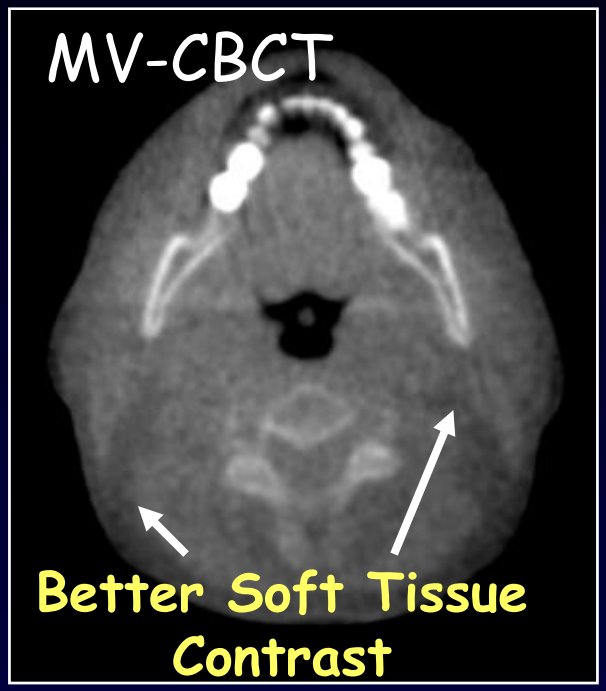


- Smallest visible bar group was 0.3 lp/mm for the 3 & 5 MU protocols
- 0.4 lp/mm for all other protocols.
- kV-CT was 0.6 lp/mm

Improved Contrast & Resolution at Higher Doses But…



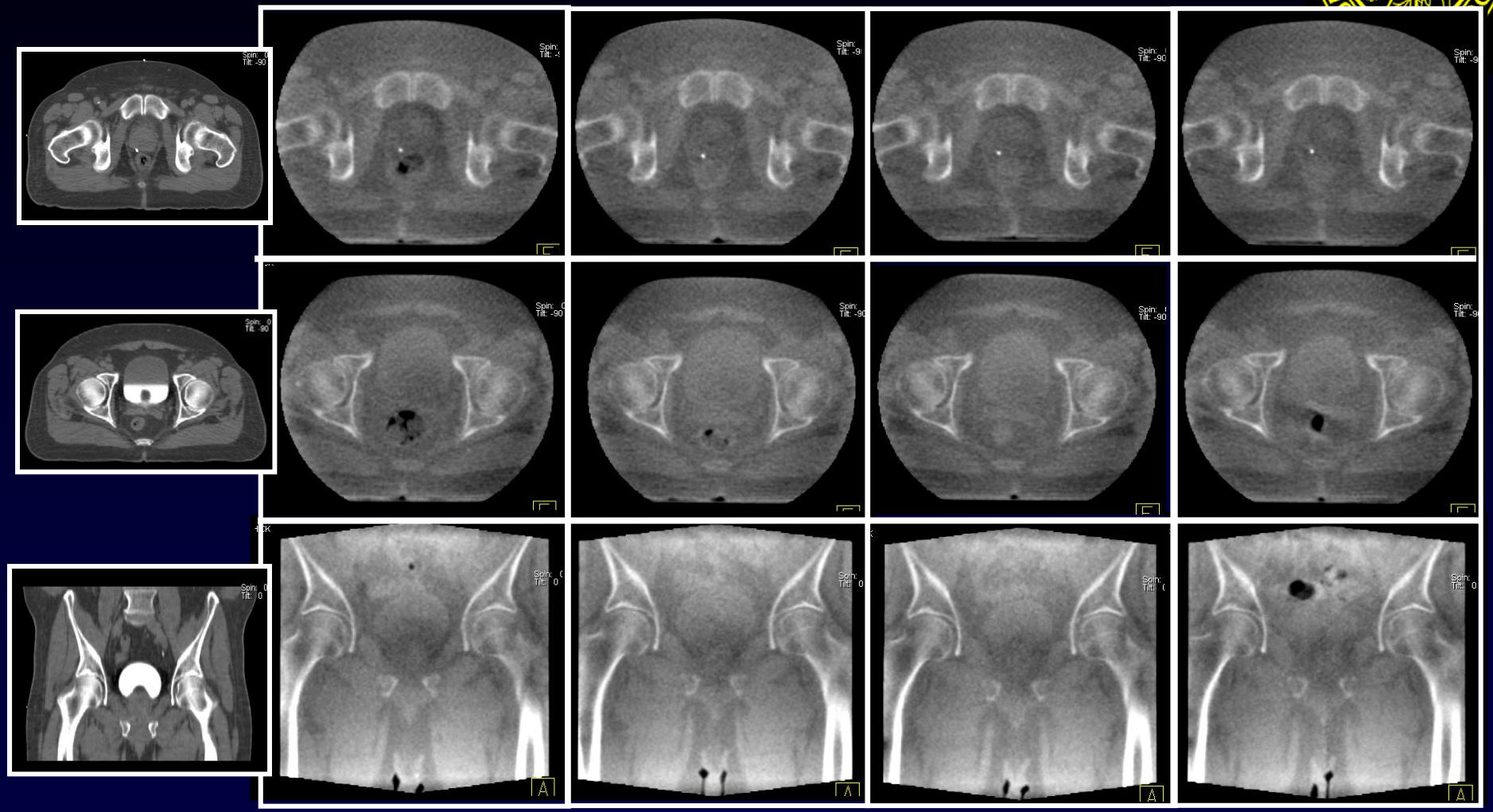




2.5 cGy 9 cGy

Sufficient bony anatomy at 2.5 cGy

Patient Imaged w/ 10 cGy



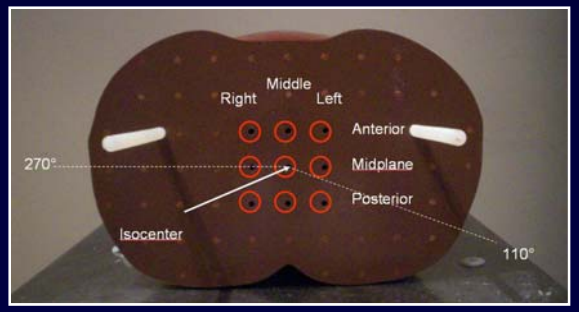
Week 1 Week 2 Week 3 Week 4

Dose Verification & Simulation

Phantom Diam.	16 cm		32 cm	
MU Protocol	10 MU		15 MU	
Method	Meas	Calc	Meas	Calc
Isocenter	7.9	8.1	9.2	9.3
0°	10.3	10.2	12.1	11.6
90°	8.9	8.7	9.7	9.5
180°	6.9	7.1	4.1	4.1
270°	8.3	8.3	8.2	8.1

Measurements and calculations are within 0.5 cGy

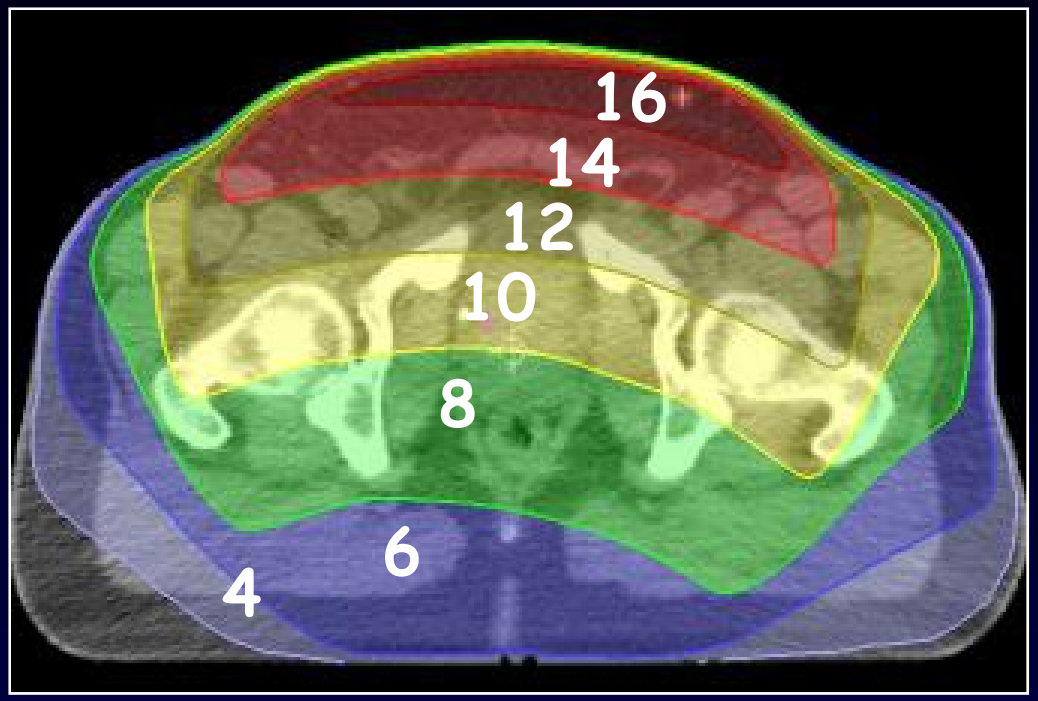
Measurements



TLD Measurements

Gayou, Parda, Johnson, and Miften, Med Phys 34, 499-506 (2007)

Imaging CB Dose Distributions

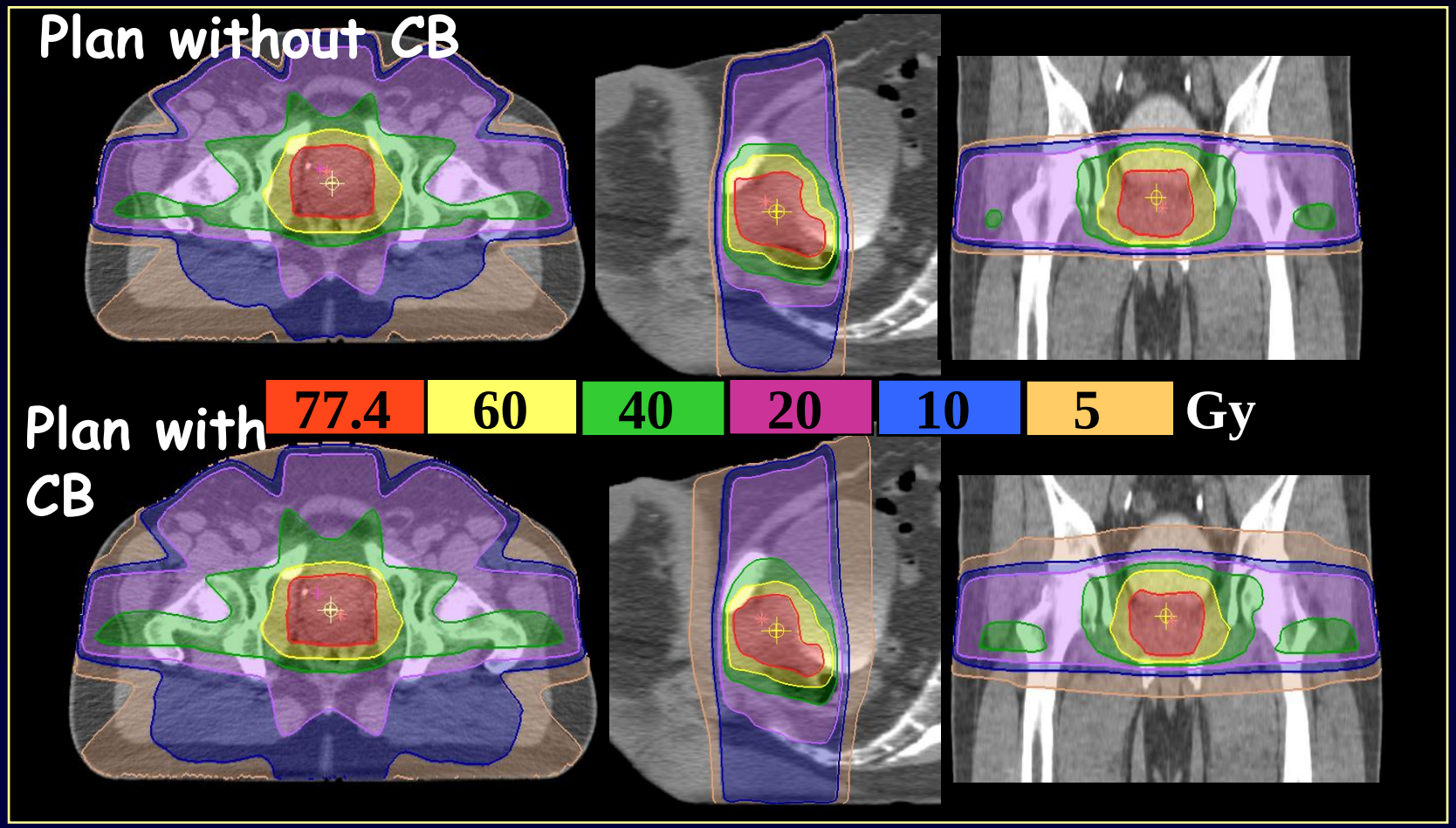


Dose in cGy

15 MU Protocol

Model the CB imaging beam as an arc beam

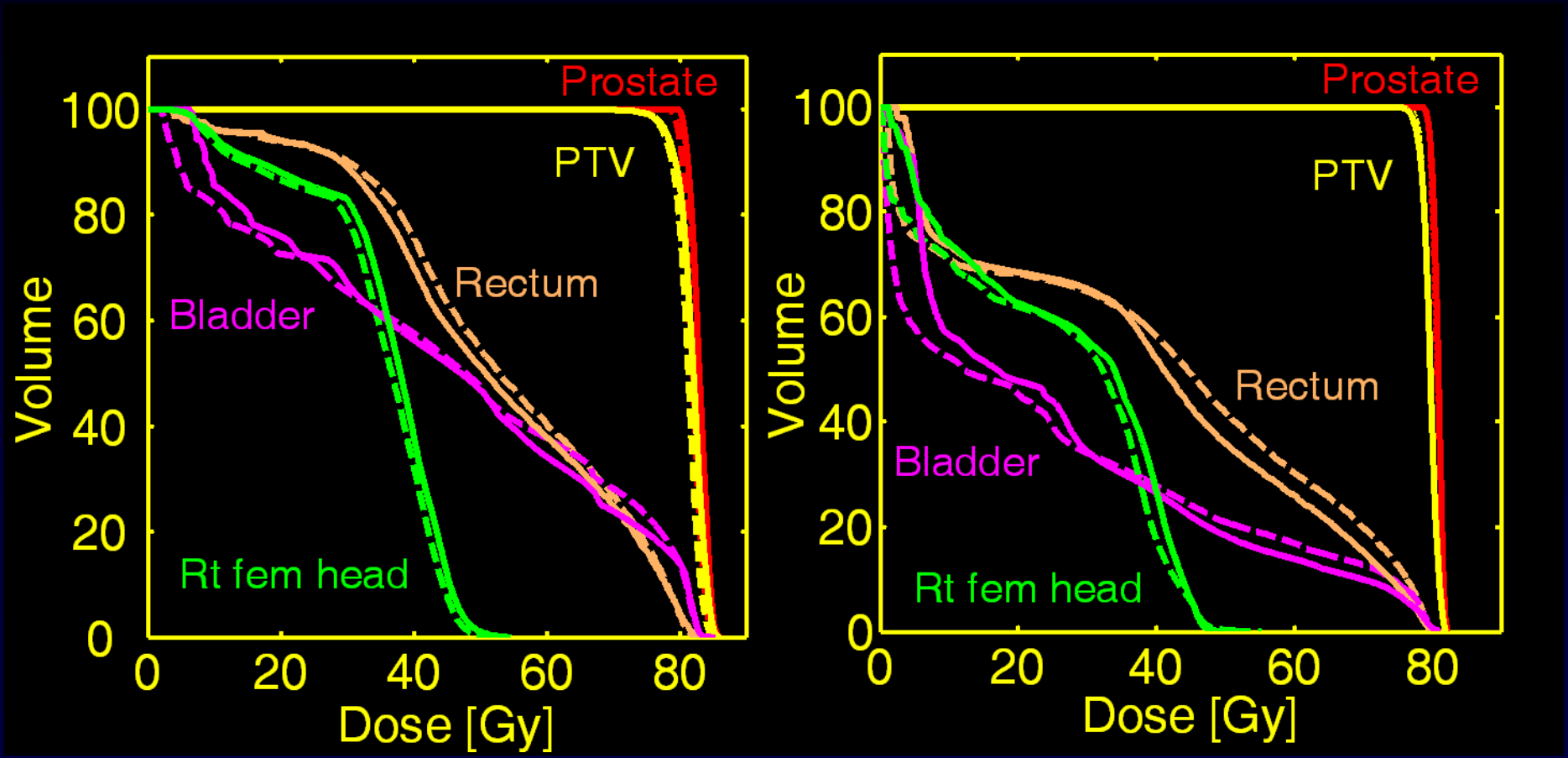
IMRT Incorporating Dose from MV-CBCT



DVHs w & w/o MV-CBCT

IMRT Plan w/o CB

IMRT Plan w/CB



Patient A

Patient B

Miften, Gayou, Reitz, et al, Med Phys 34, 3760-3766 (2007)

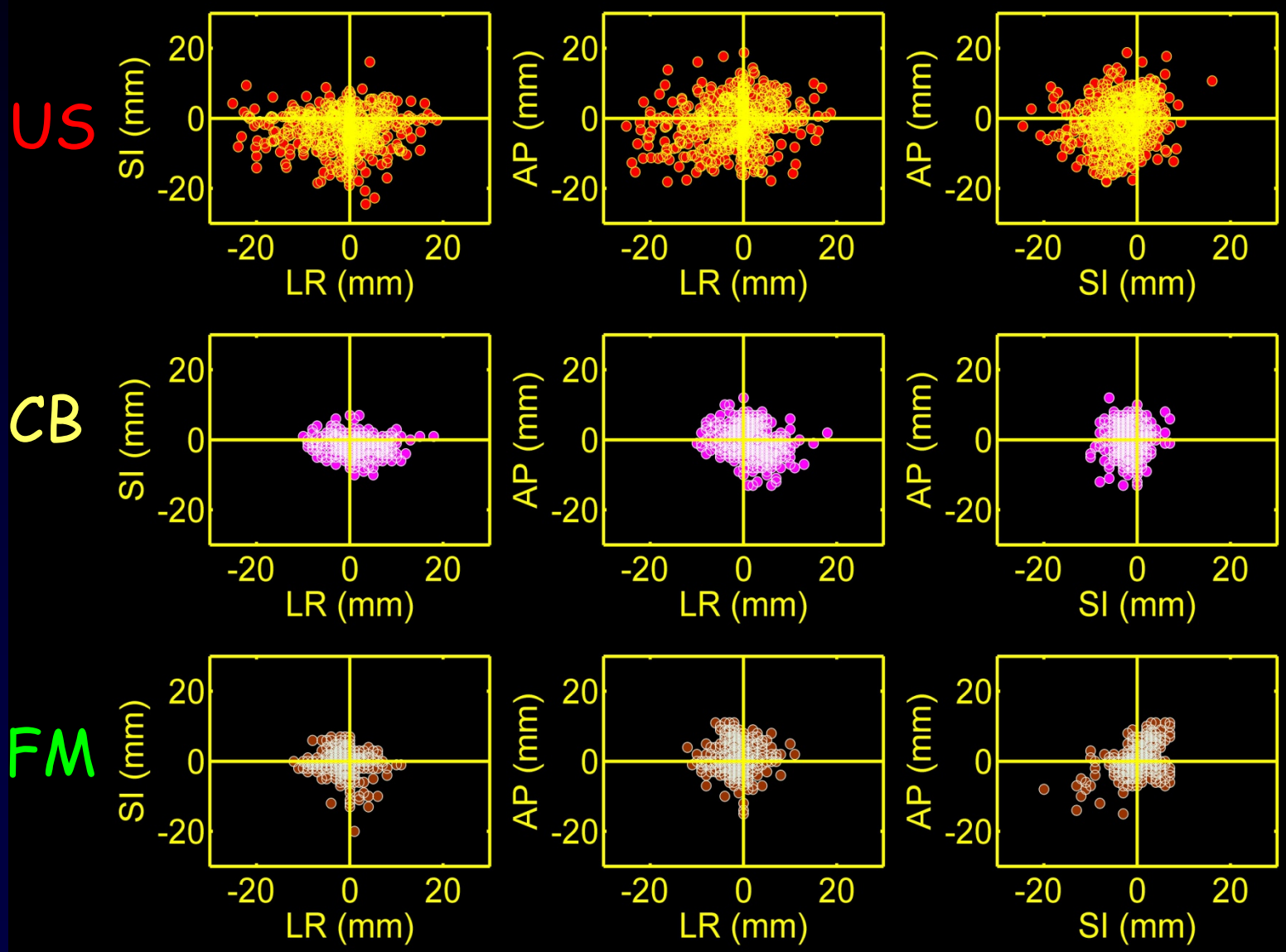
US vs. MV-CBCT vs. FM for Prostate

US: 696 couch alignments for 19 patients

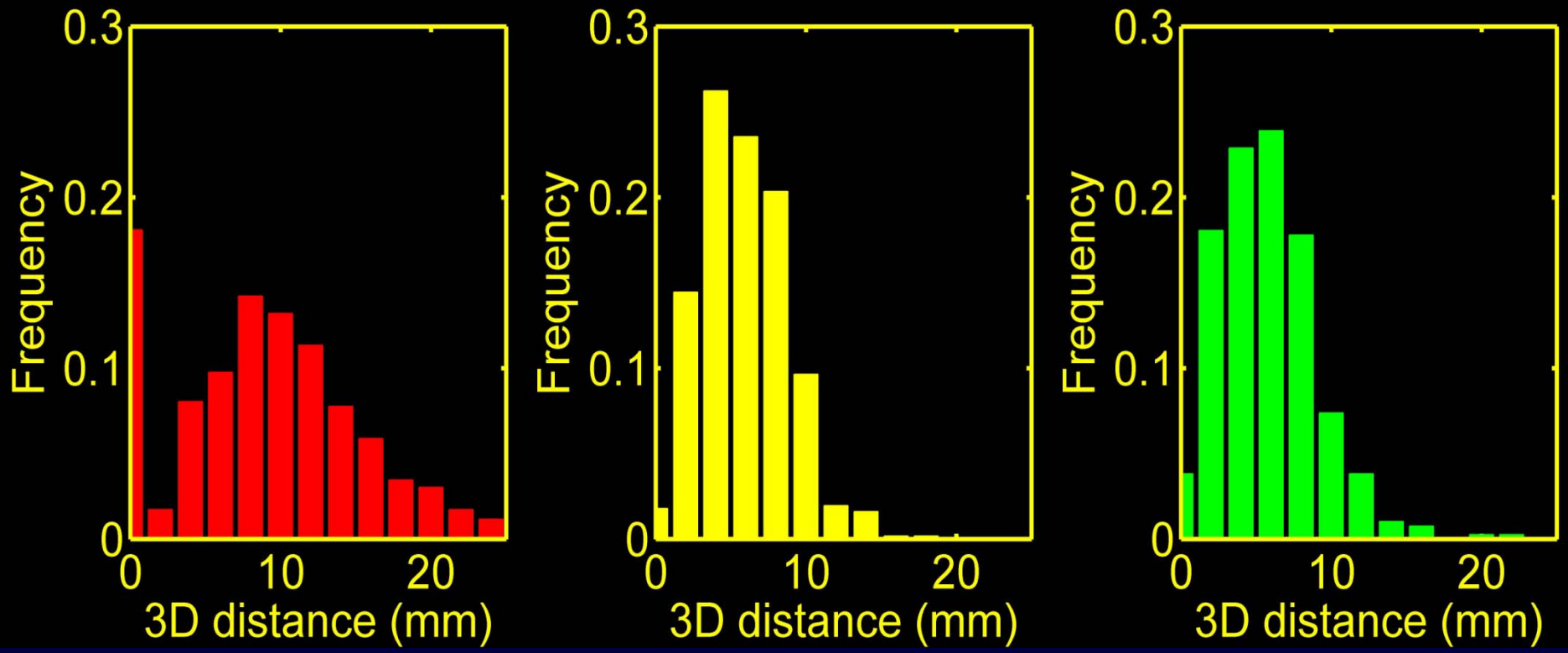
CBCT: 598 couch alignments for 17 patients

FM: 393 couch alignments for 12 patients

US vs. MV-CBCT vs. FM for Prostate



Shift Histogram Distribution



US MV-CBCT FM

Prostate Systematic & Random Errors

Localization method	AP (mm)	LR (mm)	SI (mm)
US	-1.0 ± 5.9	-1.2 ± 6.8	-2.8 ± 5.1
MV-CBCT	-0.3 ± 3.9	1.0 ± 3.9	-1.3 ± 2.5
FM	0.5 ± 4.1	-1.0 ± 3.4	0.0 ± 3.4

Percentage of Shifts Greater than 5 mm

Prostate PTV Margins

van-Herk formula: $M=2.5\Sigma+0.7\sigma$

Localization Method	AP	LR	SI
US	38%	34%	31%
MV-CBCT	16%	18%	6%
FMFM	20%	14%	10%

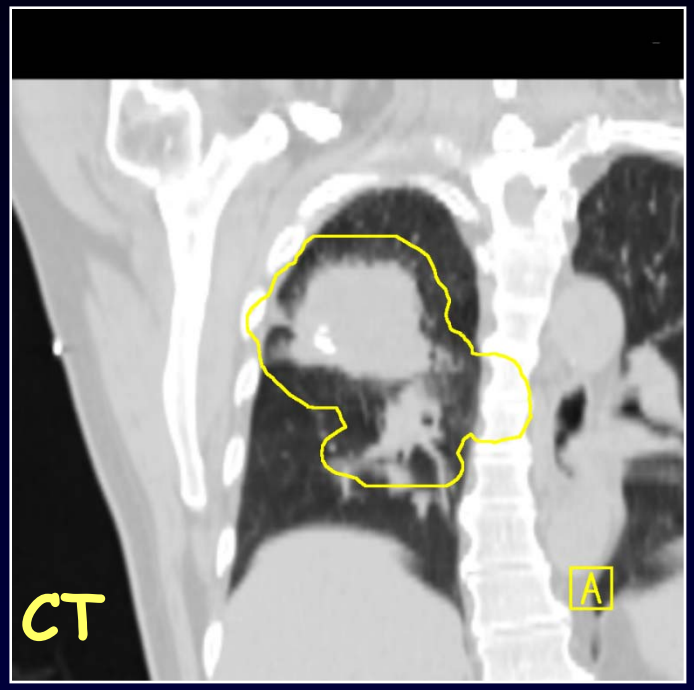
→ US data: 12.4 mm

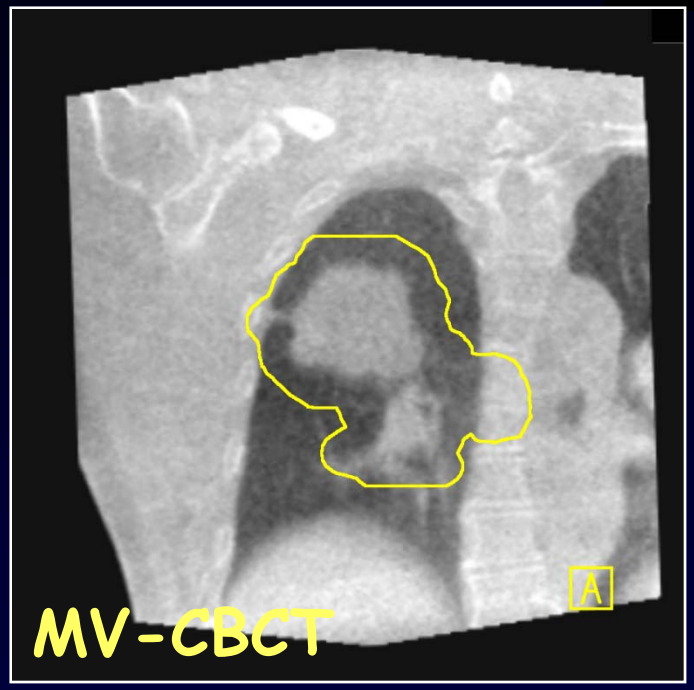
→ CB data: 8.2 mm

→ FMFM data: 6.5 mm

Gayou and Miften, Med Phys 35, 531-538 (2007)

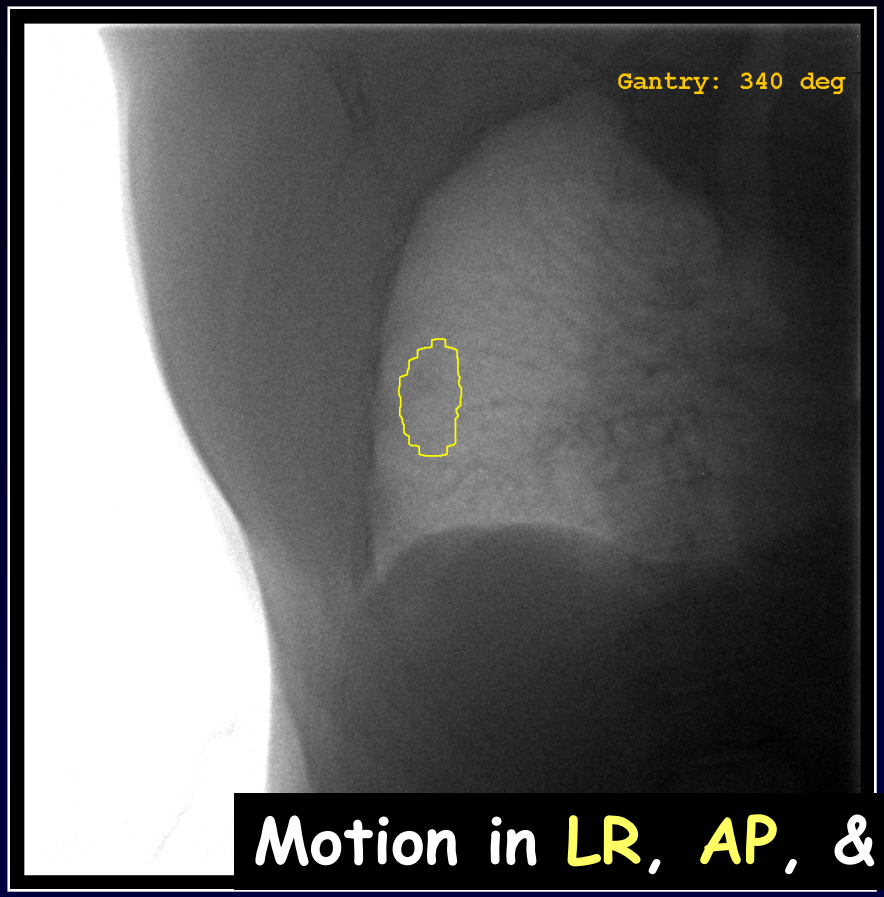
MV-CBCT: Ave Scan Over Time

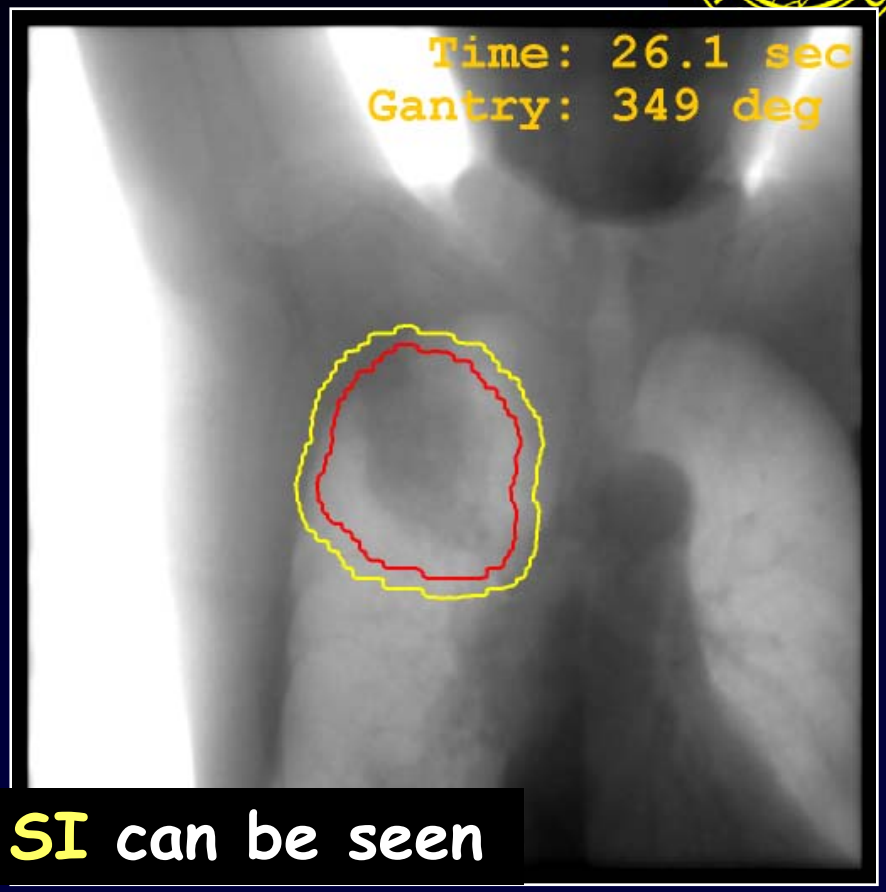




- NSCLC, right Upper Lobe, Stage IIIA T2 N2 M0
- MV-CBCT well suited for localization of tumor, but does NOT show tumor motion

Checking Motion MV-Cine





Motion in LR, AP, & SI can be seen

1 cm peripheral lung mass
Patient treated w/3DCRT

5 cm lung mass
PTV Margin: 5mm, 10mm
Patient treated w/ IMRT

Reitz, Gayou, Parda, and Miften PMB 53, 823-836 (2007)

QA Procedures & Frequency

Procedure	Daily	Monthly	2x/yr	Device
Position calibration			✓	PI, reticule
Gain calibration		✓		PI
Dead pixel map		✓		PI
EPID image quality	✓	✓		Vegas, PIPSpro
Horizontal pos. accuracy	✓			PI, reticule
Vertical pos. accuracy		✓		Ruler
Geometry calibration			✓	George phantom
CB gain calibration		✓		CB 15, 60 MU
3D image quality		✓		Ema phantom
Reconstr. & Registration		✓		Ema phantom
Dose		✓		Ion chamber

Gayou and Miften, Med Phys 34, 3183-3192 (2007)

Which Patients Should be Imaged with CB?

- Tumors adjacent to critical structures
- Tumors prone to inter-fractional motion
- Tumors with intra-fractional motion- (Preference: 4-D planning)
- Tumors prone to deformation
- Compliant patients

CBCT: Clinical Responsibilities

- Physician
  - ✓ Determine clinical indication(s)
  - ✓ Order CBCT
  - ✓ Determine frequency
  - ✓ Review images (day 1, twice/weeks, daily??)
  - ✓ Define primary ROI for physicist/therapist
  - ✓ Define set up parameters
  - ✓ Review daily shifts

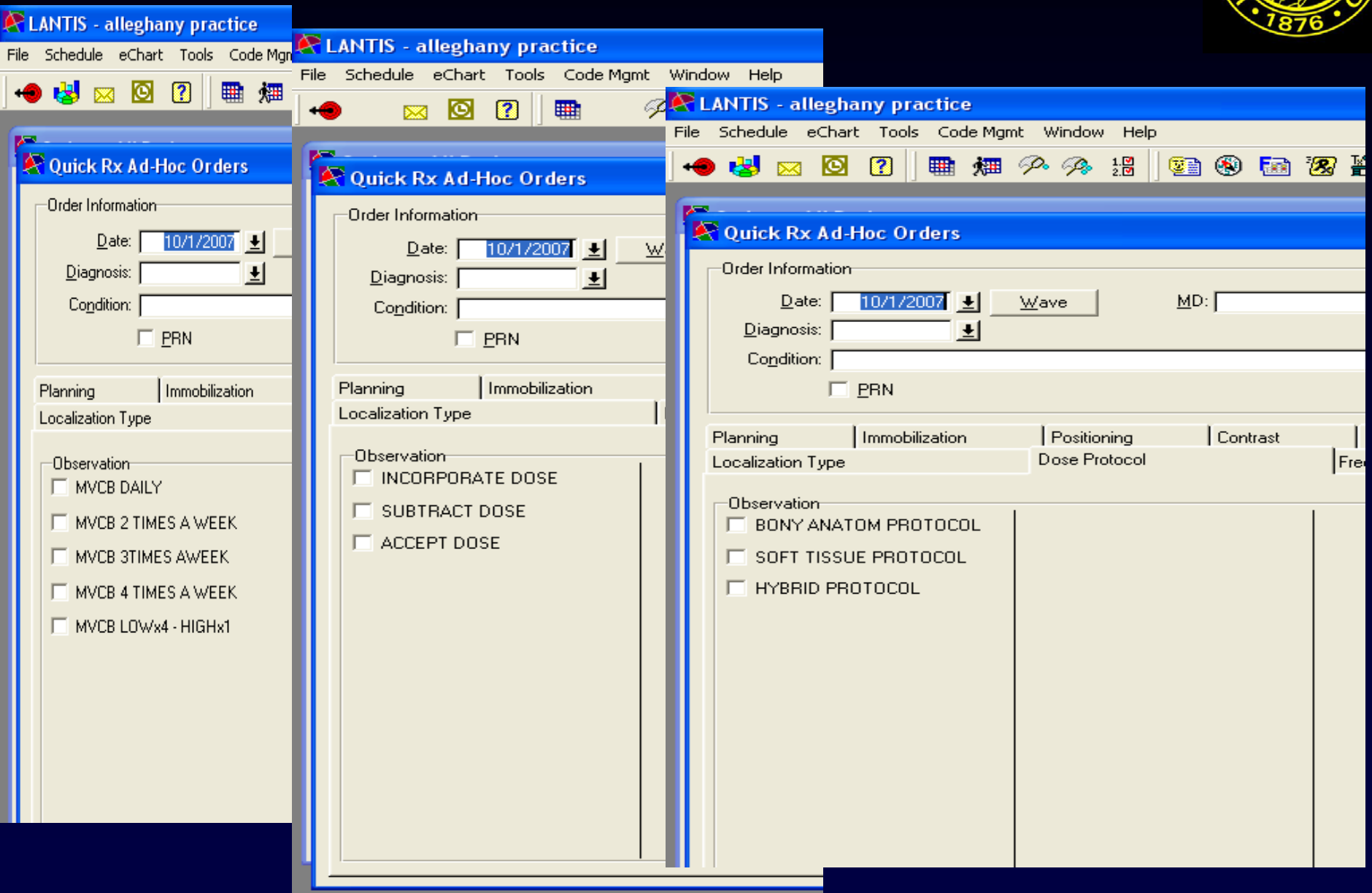
CBCT: Clinical Responsibilities

- Physicist-
  - Available to review images & shifts daily
  - QA, calibration, output, image quality…etc
- Dosimetrist –
  - Dose compensation or incorporation
- Therapist -
  - Review images
  - Make appropriate table shifts

Ordering a CB for a Patient

Physician	Daily, twice/wk, weekly	Frequency
Physician	Soft-tissue or bony anatomy	Registration
Physicist	Imaging protocol 4 MU or 8-15 MU	Exposure
Physicist Therapist	Physician by machine console for 1st Rx	Review & Thresholds

Workflow: Physician EMR Order



IGRT at the Clinic Practice Level

- Therapist oversight and competencies
- Hybrid imaging schedules
- Improve immobilization and patient marking processes
- Additional CBCT devices are needed to handle clinical needs
- Use CBCT to implement more sophisticated ART techniques
- Decrease PTV
- Improve clinical outcomes

Conclusions

- MVision is a viable tool for treatment localization
- Observed inter-fractional variations are patient specific and site-dependent
- Application of MV-CBCT for daily localization with good-image quality
- Application of MV-CBCT for verification of intra-fractional motion immediately prior to Tx

Acknowledgment

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