Quality Assurance in Radiation Therapy: Simulators & Ancillary Equipment

ICPT School on Medical Physics for Radiation Therapy

Justus Adamson PhD
Assistant Professor
Department of Radiation Oncology
Duke University Medical Center

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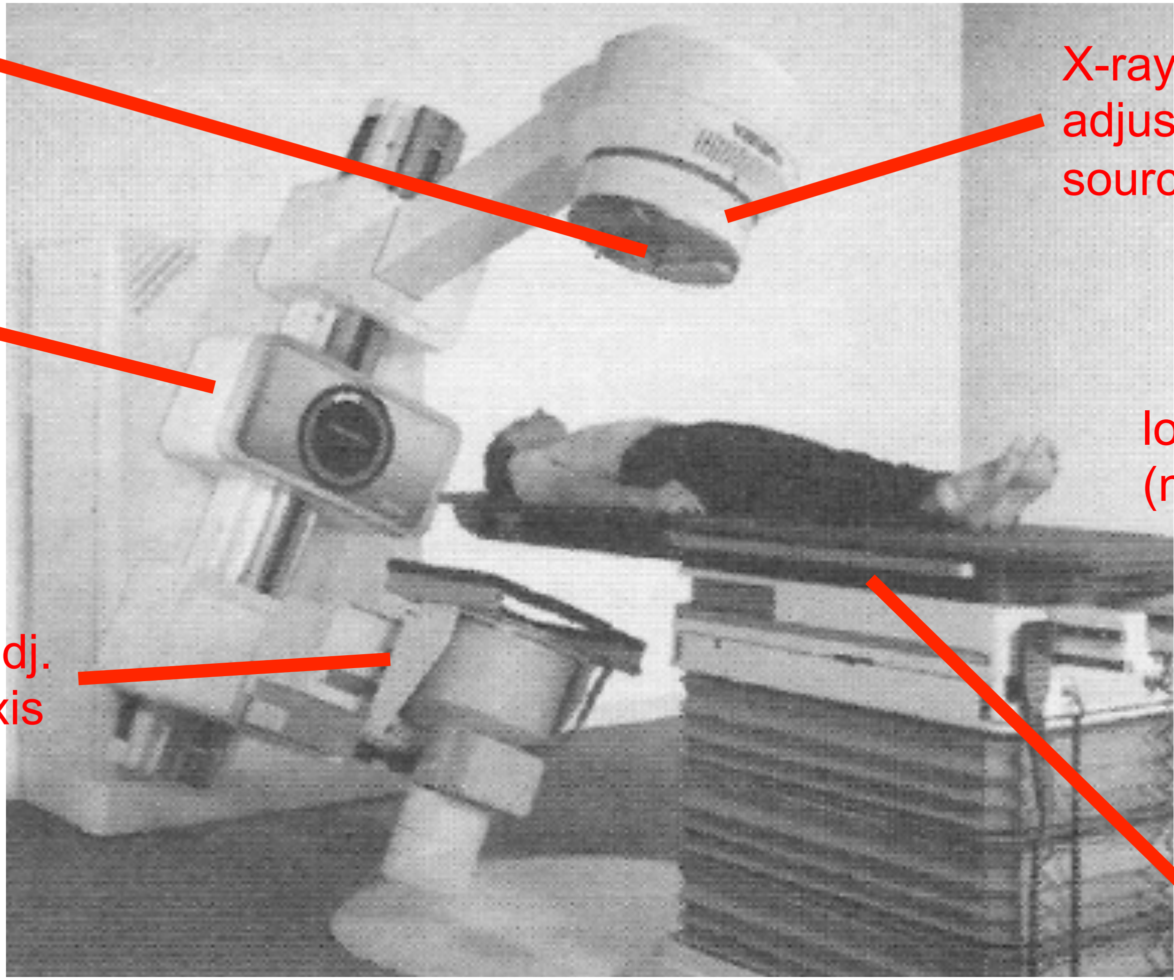
Topics

Overview & Quality Assurance of:

- Radiographic Simulators
- CT-Simulators
- MV image guidance
- kV image guidance
- Patient support systems
- Patient immobilization devices

Radiographic Simulators



Radiographic Simulators

X-ray source with adjustable collimation

CBCT capability

field light

rotating gantry

patient support assembly

Imager with adj. distance to axis

localizing laser (not shown)

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Radiographic Simulators: Components & Purpose

- Components:
  - Imaging source & detector
  - Localizing lasers
  - Optical distance indicator
  - Field light
  - Patient support assembly
- Purpose: to reproduce the geometric conditions of the radiation therapy equipment
  - Should be subject to the same mechanical checks as linear accelerators
  - Image quality should be checked following guidelines for diagnostic radiography

Radiographic Simulators QA: Reports, Recommendations, & Guidelines

- AAPM:
  - Report 46, Task Group 40, “Comprehensive QA for Radiation Oncology” (1994)
  - http://www.aapm.org/pubs/reports/RPT_46.PDF

Radiographic Simulators QA:
Recommended Frequency & Tolerances (AAPM)

TABLE III. QA of simulators.

Frequency	Procedure	Tolerance[a]
Daily	Localizing lasers	2 mm
	Distance indicator (ODI)	2 mm
Monthly	Field size indicator	2 mm
	Gantry/collimator angle indicators	1 deg
	Cross-hair centering	2 mm diameter
	Focal spot-axis indicator	2 mm
	Fluoroscopic image quality	Baseline
	Emergency/collision avoidance	Functional
	Light/radiation field coincidence	2 mm or 1%
	Film processor sensitometry	Baseline
Annual	Mechanical Checks	
	Collimator rotation isocenter	2 mm diameter
	Gantry rotation isocenter	2 mm diameter
	Couch rotation isocenter	2 mm diameter
	Coincidence of collimator, gantry, couch axes and isocenter	2 mm diameter
	Table top sag	2 mm
	Vertical travel of couch	2 mm
	Radiographic Checks	
	Exposure rate	Baseline
	Table top exposure with fluoroscopy	Baseline
	Kvp and mAs calibration	Baseline
	High and low contrast resolution	Baseline

[a]The tolerances mean that the parameter exceeds the tabulated value (e.g., the measured isocenter under gantry rotation exceeds 2 mm diameter).

essentially the same as linac

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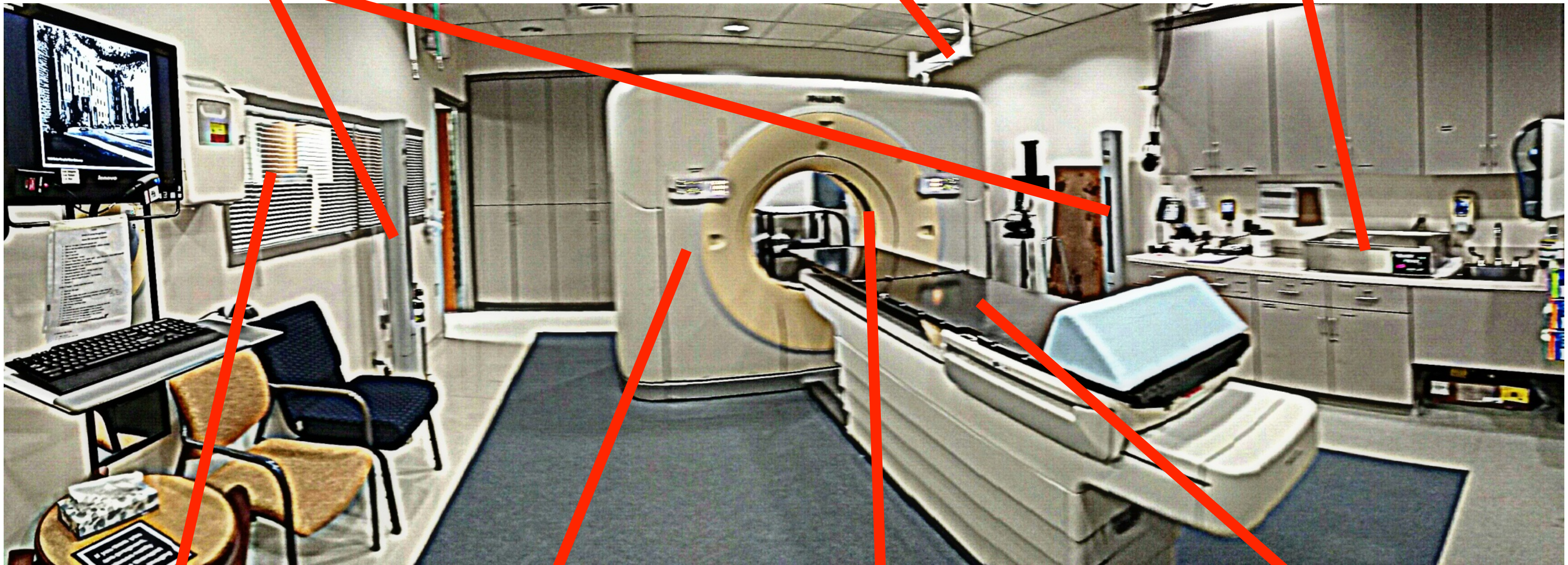
AAPM Report 46, Task Group 40, "Comprehensive QA for Radiation Oncology" (1994)

CT Simulators

External lasers for marking origin/isocenter

CT contrast injector

water bath for thermoplastic masks



CT control room

CT bore

Internal CT lasers

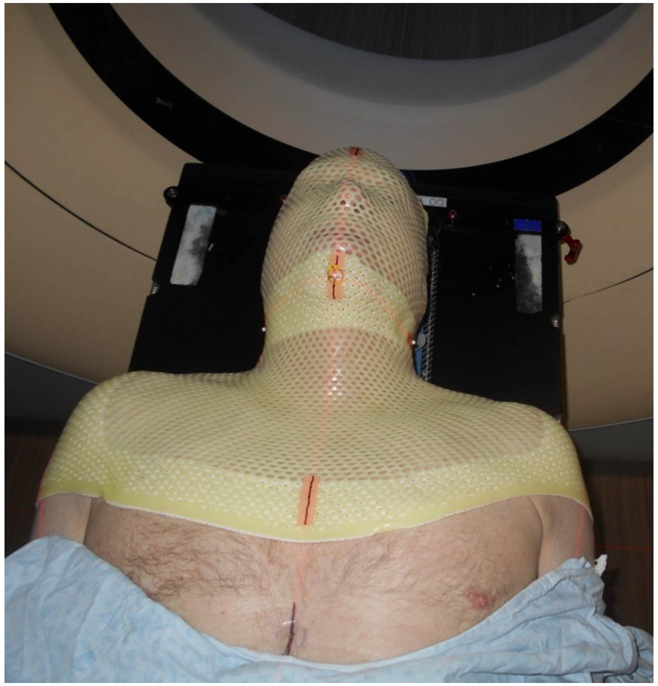
flat patient support table

CT Simulation Process

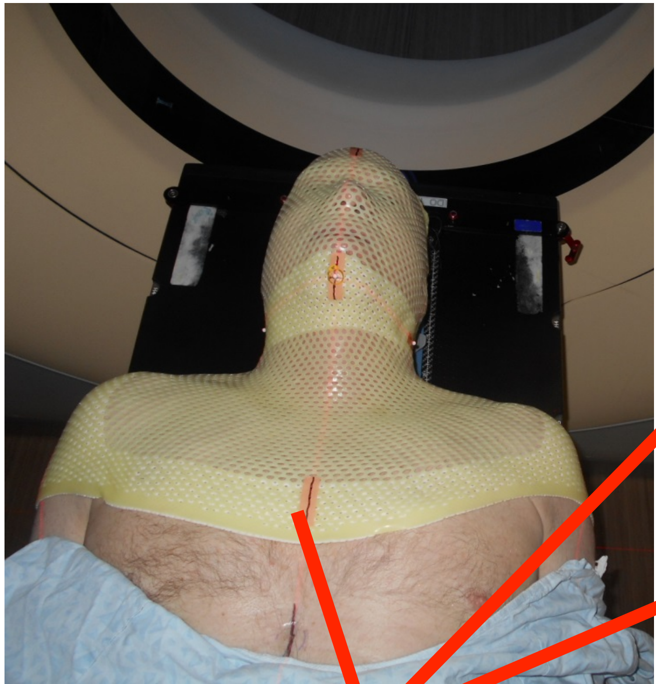
1. CT Scan, patient positioning, immobilization
    1. similar to diagnostic CT
    2. added requirements of localization (lasers) & immobilization
2. Treatment planning & CT simulation
    1. performed in treatment planning system: contouring, isocenter placement, selection of treatment geometry, documentation
3. Treatment setup
    1. setup at machine according to instructions from CT-simulation & treatment planning

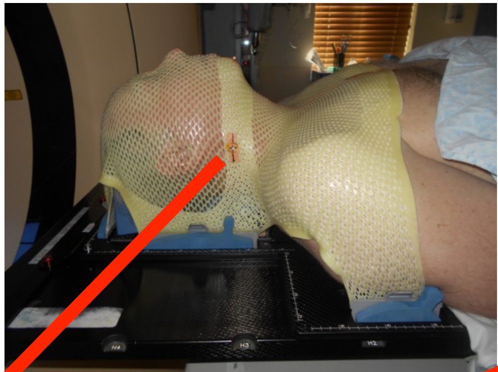
Simulation Process at CT

- Patient aligned in treatment position
- Immobilization prepared
- Laser origin marked (location of lasers during CT)
- CT image acquired
- Isocenter marked (optional)
- Patient setup instructions recorded

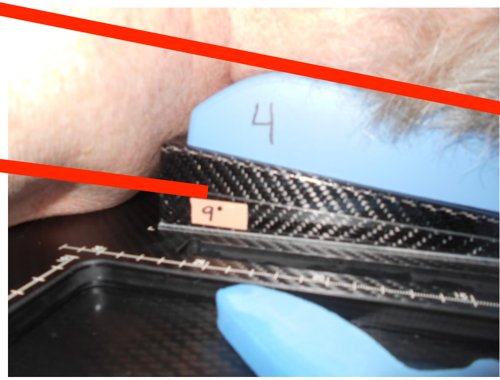


CT Simulation Setup Examples:





laser location
Marked
(often fiducials placed for CT)



Immobilization
details noted

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CT Simulator: Components

- Bore / CT apparatus
- Internal/external localizing lasers
- Patient support (flat table top to mimic treatment table)

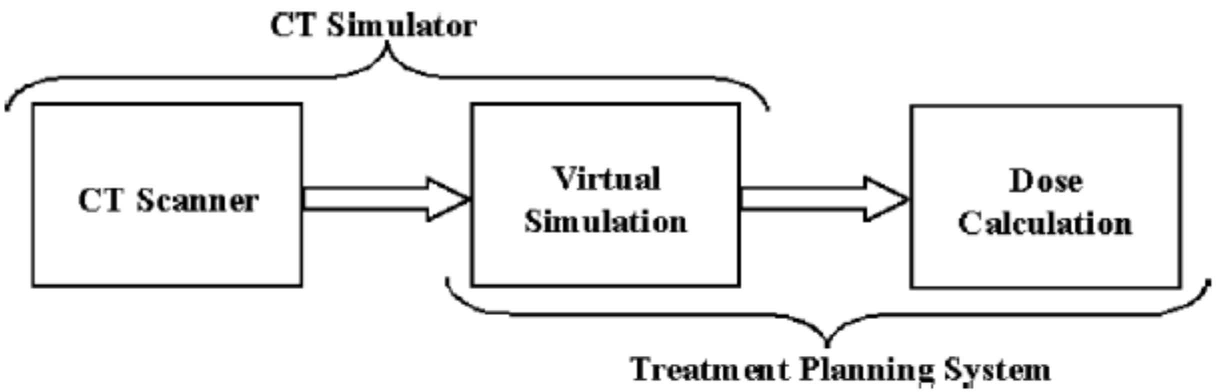


FIG. 1. Block diagram showing relevant components of CT-simulation and treatment planning systems.

AAPM Report 83, Task Group 66, "Quality assurance for computed-tomography simulators and the computed tomography simulation process" (2003)

QA of CT Simulators: Reports, Recommendations, & Guidelines

- AAPM:
  - Report 46, Task Group 40, "Comprehensive QA for Radiation Oncology" (1994)
    - http://www.aapm.org/pubs/reports/RPT_46.PDF
  - Report 83, Task Group 66, "Quality assurance for CT and the CT simulation process" (2003)
    - http://www.aapm.org/pubs/reports/RPT_83.pdf
  - Report 39, Task Group 2, "Specification and Acceptance Testing of Computed Tomography Scanners" (1993)
    - http://aapm.org/pubs/reports/RPT_39.pdf

CT Simulators: AAPM TG66 Recommended QA

- Radiation Safety: shielding survey
- Radiation dosimetry: CTDI
- Lasers: alignment with imaging planes
- Tabletop:
  - alignment with imaging planes
  - indexing & position
- Gantry tilt accuracy
- Scan localization
- CT dosimetry:
  - dose from CT scan (CTDI)
  - radiation profile width
  - sensitivity profile width
- Generator tests

Imaging tests:

- CT number accuracy
- Image noise
- In plane spatial integrity
- Field uniformity
- Electron density to CT conversion
- Spatial resolution
- Contrast resolution

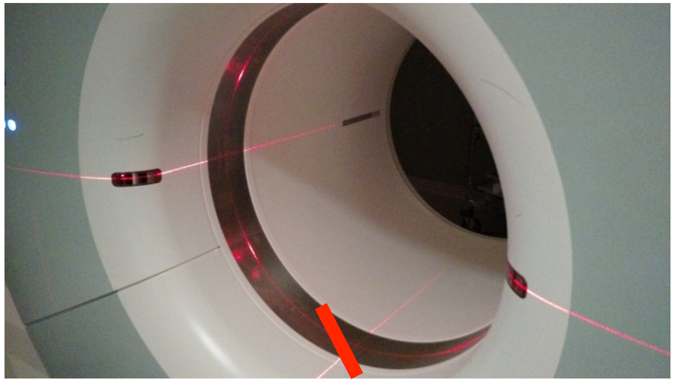
AAPM Report 83, Task Group 66, "Quality assurance for computed-tomography simulators and the computed tomography simulation process" (2003)

CT Simulator QA: Laser Alignment

- Three sets of lasers:

distance between external lasers and the gantry (& imaging plane) is typically fixed at 50cm

gantry lasers



gantry lasers should accurately identify scan plane

& should be parallel and orthogonal with scan plane & intersect center

wall mounted lasers (external)

overhead sagittal laser (external)

external lasers should be accurately spaced from imaging plane
& should be parallel and orthogonal with scan plane & intersect at a point co-incident with center

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CT Simulator QA: Laser Alignment

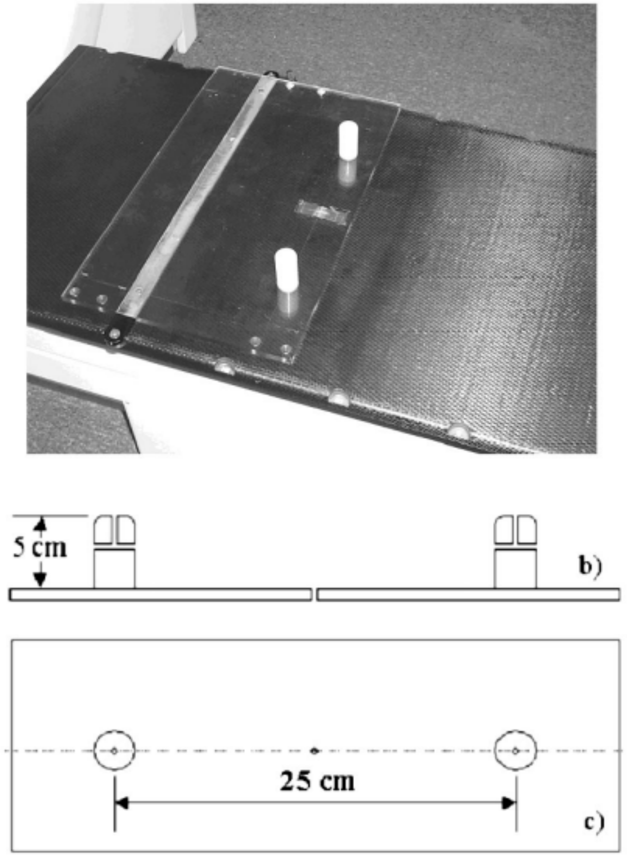

FIG. 4. (a) CT-simulator laser QA device attached to the table top using a registration bar; (b) diagram of the side view of the device through the center of two pegs showing holes drilled inside the pegs; (c) diagram of the top view of the device.

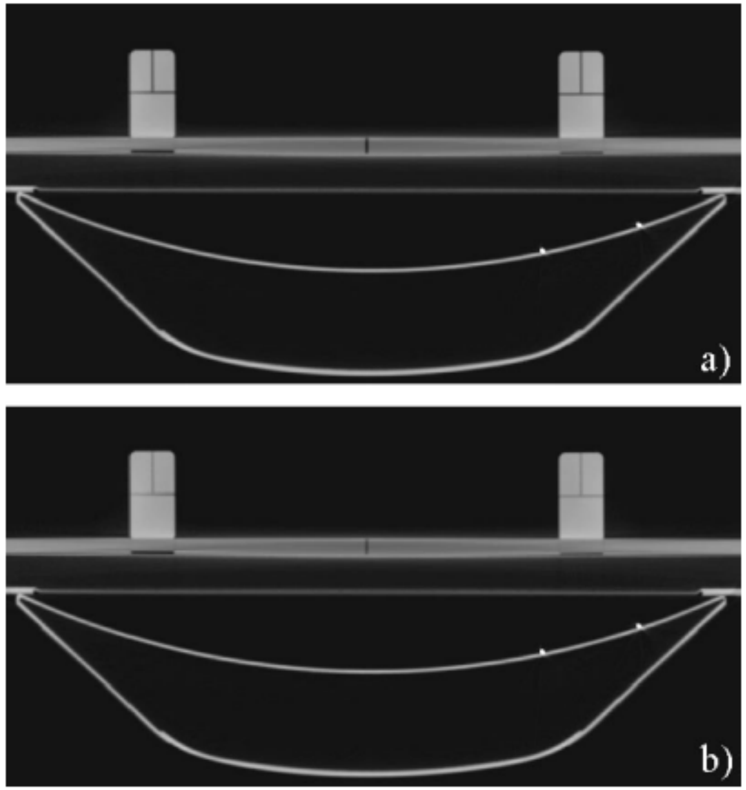

FIG. 8. CT image of laser QA device. (a) lasers aligned with imaging plane. (b) center of the QA device offset by 1 mm from the imaging plane.

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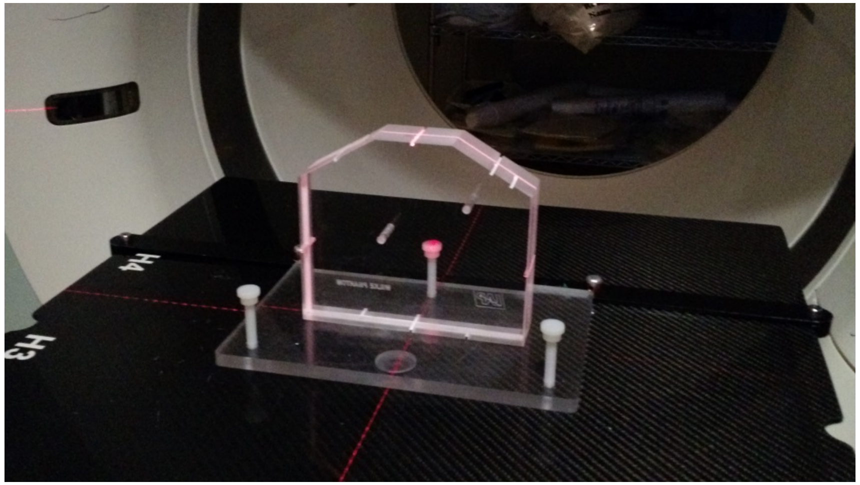
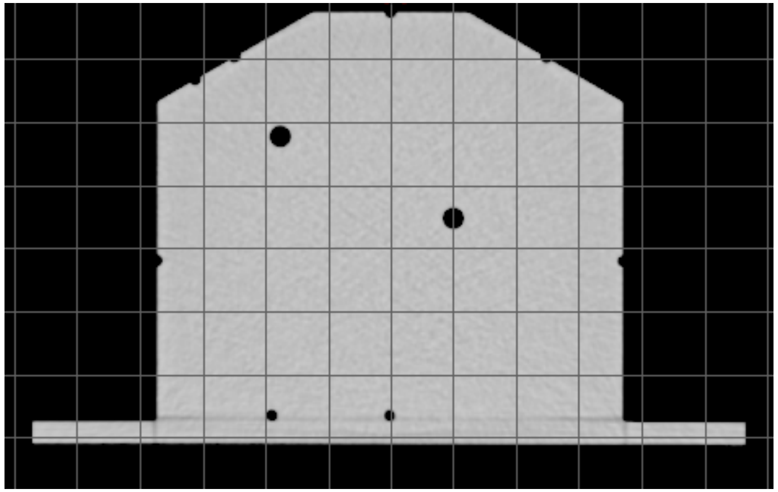
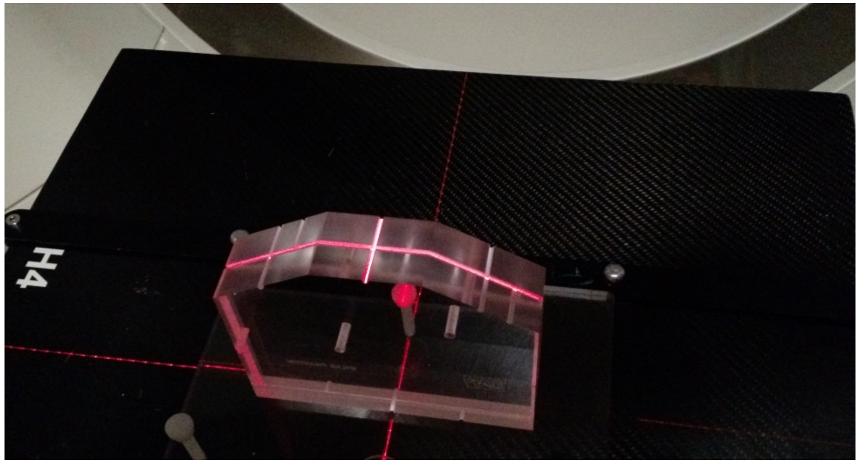
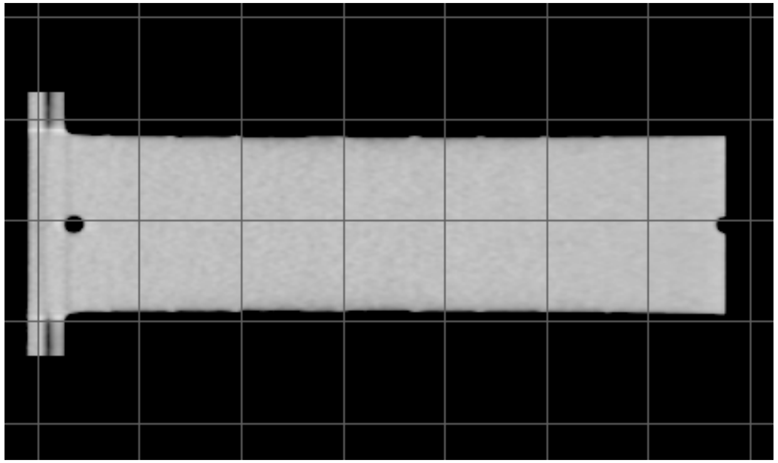
AAPM Report 83, Task Group 66, “Quality assurance for computed-tomography simulators and the computed tomography simulation process” (2003)

CT Simulator QA: Laser Alignment









CT Simulator QA: Laser Motion

- External lasers can often be shifted to mark a new isocenter after CT
- Laser motion should be accurate, linear, & reproducible

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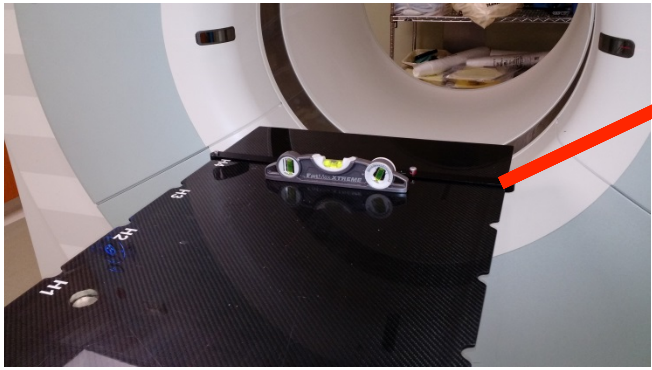
CT Simulator QA: Tabletop

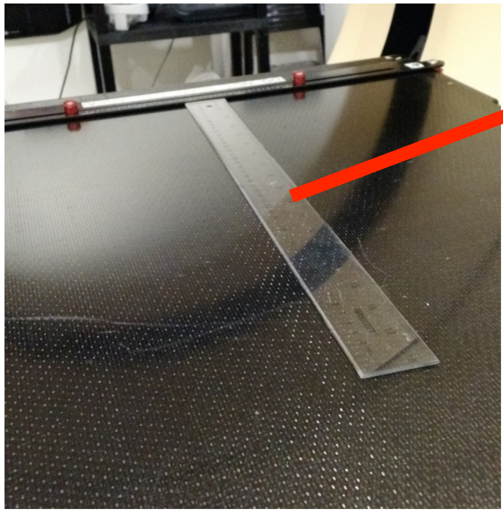
- (often) has ability to “register” immobilization devices at specified positions
- Necessary criteria:
  - should mimic treatment table
  - flat, level, orthogonal
  - similar sag properties
  - motion indicators & table position should be accurate & reproducible

interlocking immobilization devices

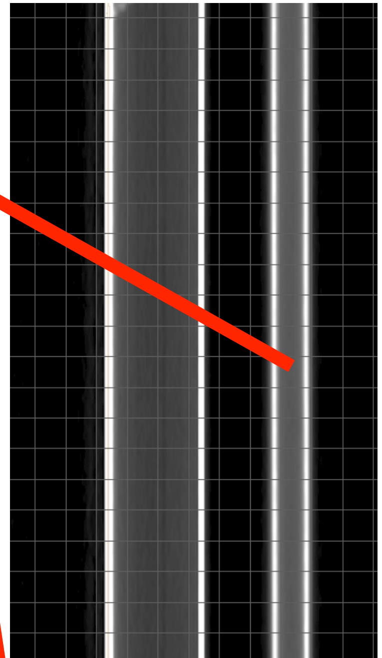
CT Simulator QA: Tabletop

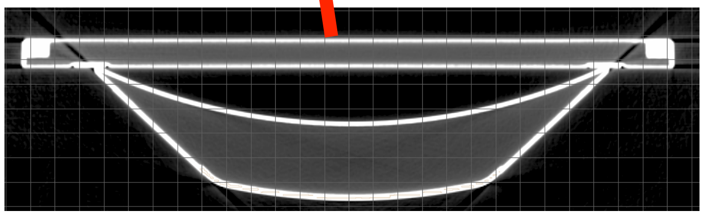


ensure table is level relative to both gravity & imaging plane



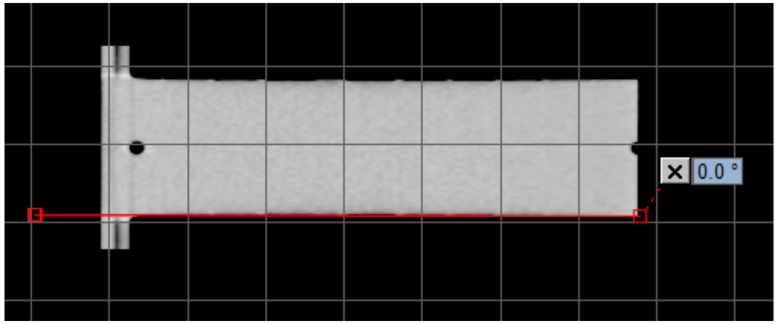
verify accuracy of longitudinal & vertical table motion





CT Simulator QA: Gantry Tilt

- Many CT gantries can be tilted for diagnostic scans
  - not typically used for CT simulations
- Accuracy of tilt (especially at 0°) should be verified
  - TG66 recommendation: verify with film
- Suggestion: mark the external laser position on the scanner with the gantry level



CT Simulator QA: Scan Localization (from Scout Image)

- Scan range is defined using a scout image
- Verify actual scanned volume corresponds to requested scan volume
- Also verify radiation & sensitivity profile

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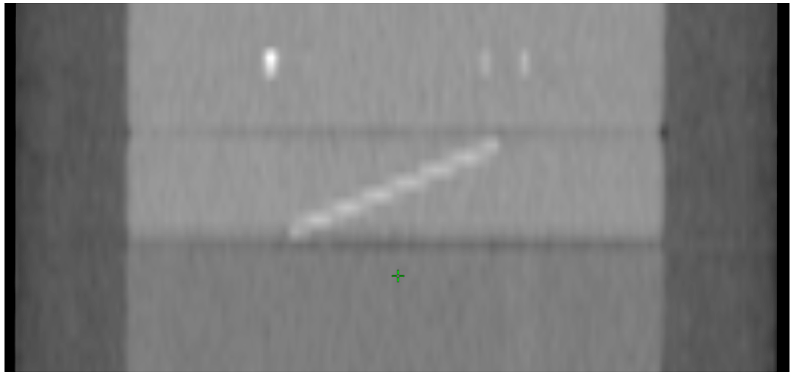
CT Simulator QA: Radiation Profile

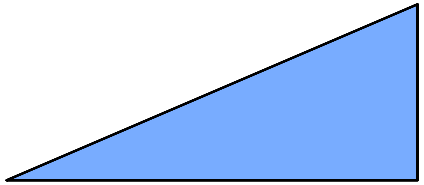
- evaluates “pre-patient” collimation
- dose profile prior to detector collimation
- excessively wide radiation profile can result in unnecessary patient dose
- excessively narrow radiation profile can result in increased quantum noise
- measurement: full width at half maximum of exposed film (measured for each slice thickness)

CT Simulator QA: Sensitivity Profile

- evaluates “post-patient” collimation (it is a function of pre- and post- patient collimation)
- defines actual width of imaged slice
- excessive sensitivity profile width can lead to loss of resolution in longitudinal direction
- excessively narrow sensitivity profile can result in increased quantum noise
- measurement:
  - use inclined metal ramp
  - length of ramp in image slice can be used to calculate slice thickness

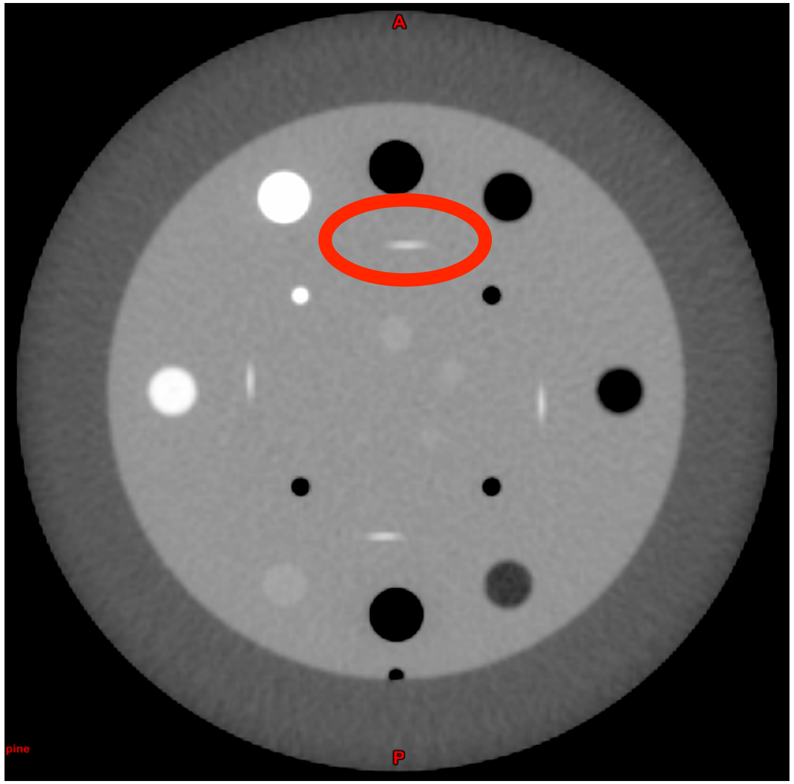


$$W_s = t \cdot \tan(\theta)$$

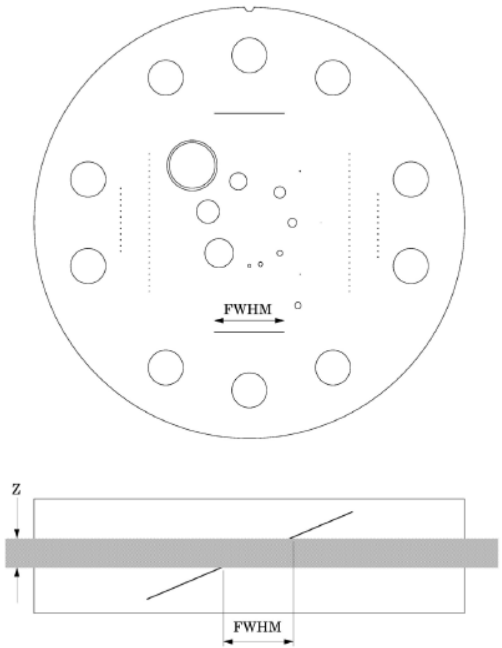


Catphan manual

CT Simulator QA: Sensitivity Profile



Slice width measurement with wire ramps



The 23° wire ramp angle is chosen to improve measurement precision through the trigonometric enlargement of 2.38 in the x-y image plane.

To evaluate the slice width (Zmm), measure the Full Width at Half Maximum (FWHM) length of any of the two wire ramps and multiply the length by 0.42:

(Zmm) = FWHM * 0.42

Catphan 700 manual

CT Simulator QA: CTDI

- CTDI: Integrated dose (along z-axis) from one axial CT slice
- $CTDI_{100mm}$ is what is measured in practice
- CTDI is usually ~2x higher at the surface
- Dose Length Product (DLP): defines total energy absorbed by a scanned volume:

$$\text{DLP}\ (\text{mGy cm}) = \text{CTDI}_{vol}(\text{mGy}) \cdot \text{scan length}\ (\text{cm})$$

$$\text{CTDI}_{FDA} = \frac{1}{nT}\int_{-7T}^{+7T} D(z)\,dz,$$

$CTDI_w$ = 2/3 $CTDI_{100}$(surface) + 1/3 $CTDI_{100}$(center)

N=number of simultaneous axial scans per rotation (multi-slice CT)

Axial:

$$\text{CTDI}_{vol} = \frac{N \cdot T}{I} \cdot \text{CTDI}_w,$$

I=table increment per axial scan

T=thickness of one axial scan

Helical:

$$\text{CTDI}_{vol} = \frac{1}{\text{pitch}} \cdot \text{CTDI}_w$$

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AAPM Report 83, Task Group 66, "Quality assurance for computed-tomography simulators and the computed tomography simulation process" (2003)

CT Simulator QA: CTDI

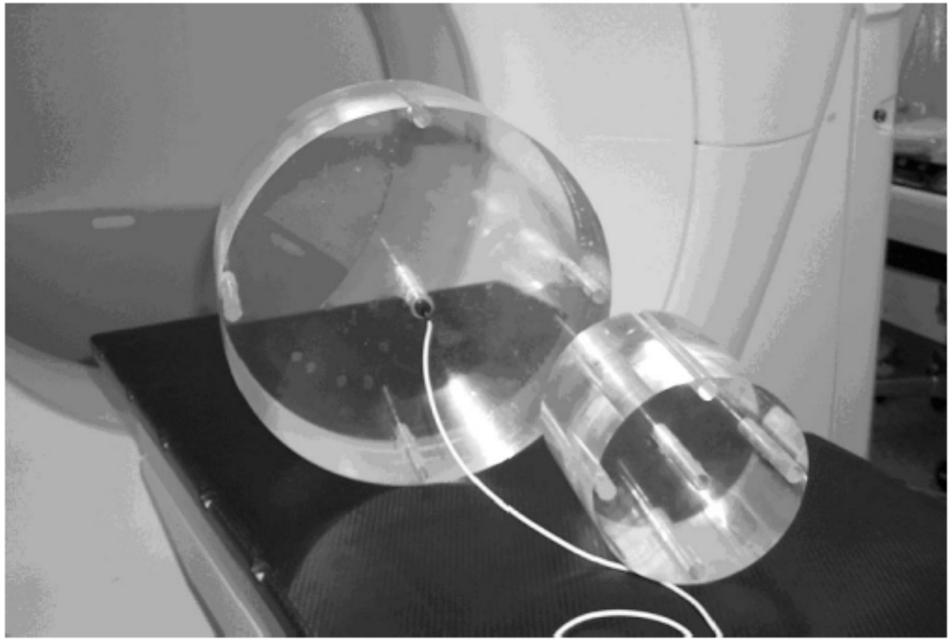

FIG. 7. A body and head phantom for measurement of dose from CT-scans. Pencil ionization chamber is inserted in the center of the body phantom.

- 2 phantoms utilized:
  - head:
    - length=15cm
    - diameter=16cm
  - body
    - length=15cm
    - diameter=32cm
  - holes for chamber:
    - central hole
    - 4-8 periphery holes

$$\mathrm{CTDI}_{100} = \frac{\mathrm{Rdg} * C_{tp} * K_{\mathrm{el}} * N_x * f_{\mathrm{med}} * 100(\mathrm{mm})}{\mathrm{Total\ nominal\ beam\ width}(\mathrm{mm})} [\mathrm{cGy}],$$

AAPM Report 83, Task Group 66, "Quality assurance for computed-tomography simulators and the computed tomography simulation process" (2003)

CT Simulator QA: CTDI

chamber exposure calibration factor (R/C)

electrometer correction (C/Rdg)

converts exposure in air to absorbed dose in medium. (0.94 cGy/R for muscle @ E_{eff}=70keV)

temperature & pressure correction

$$\mathrm{CTDI}_{100}=\frac{\mathrm{Rdg}*C_{tp}*K_{\mathrm{el}}*N_x*f_{\mathrm{med}}*100(\mathrm{mm})}{\text{Total nominal beam width(mm)}}[\mathrm{cGy}],$$

AAPM Report 83, Task Group 66, "Quality assurance for computed-tomography simulators and the computed tomography simulation process" (2003)

CT Simulator QA: Generator Tests

- Tests include:
  - peak potential (kVp)
  - half value layer (HVL)
  - mAs linearity
  - mAs reproducibility
  - time accuracy
  - (possible focal spot size)
- Measurement preferences:
  - Non-invasive measurement preferred
  - Performed with kV tube "parked"

CT Simulators: AAPM TG66 Recommended QA

Component	Frequency	Tolerance
Radiation safety survey	initially	regulatory limits
Patient dosimetry from CT (CTDI)	annually & after component replacement	±20% manufacturer specs
Laser alignment	daily/monthly & after laser adjustment	±2mm
Table: orientation relative to imaging plane	monthly & after laser adjustment	±2mm
Table: vertical & long. motion	monthly	±1mm
Table: indexing & position	annually	±1mm
Gantry tilt accuracy	annually	±1°
Scan localization	annually	±1mm
Radiation profile width	annually	manufacturer specs
Sensitivity profile width	semi-annually	±1mm
Generator tests	initially & after component replacement	manufacturer specs

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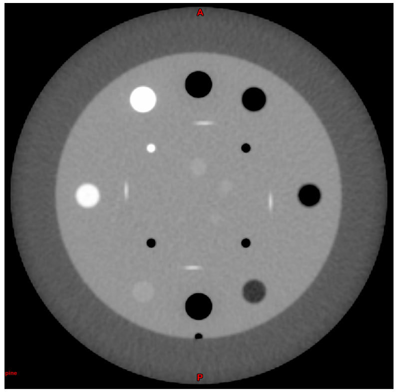
CT Simulators:
AAPM TG66 Recommended Imaging Tests

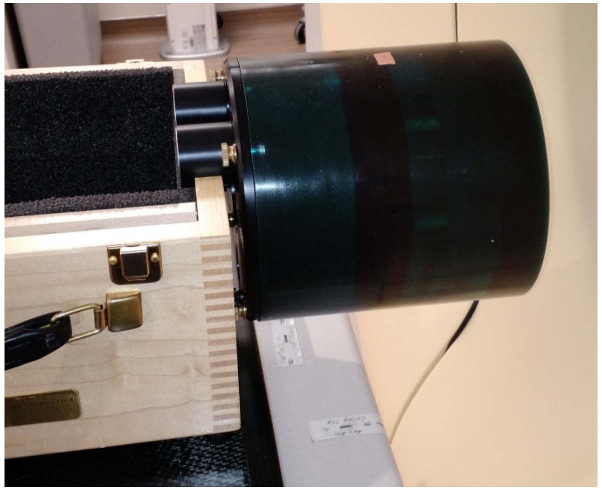
- CT number accuracy
- Image noise
- In plane spatial integrity
- Field uniformity
- Electron density to CT conversion
- Spatial resolution
- Contrast resolution

AAPM Report 83, Task Group 66, "Quality assurance for computed-tomography simulators and the computed tomography simulation process" (2003)

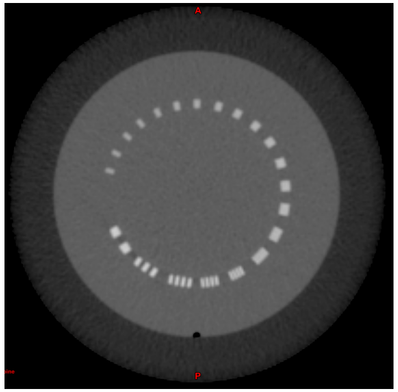
CT Simulator Imaging QA:

CT# accuracy & in plane spatial integrity

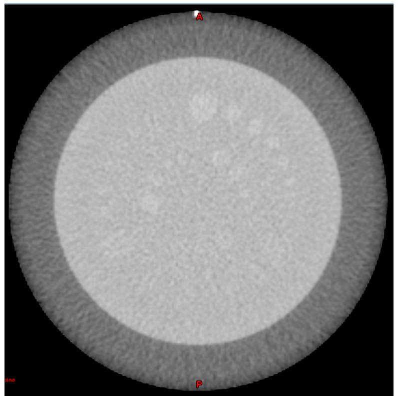




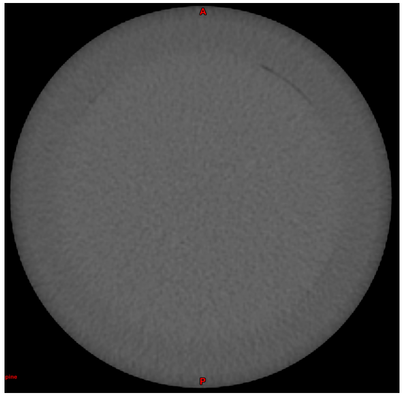
high contrast resolution



low contrast resolution



uniformity & noise



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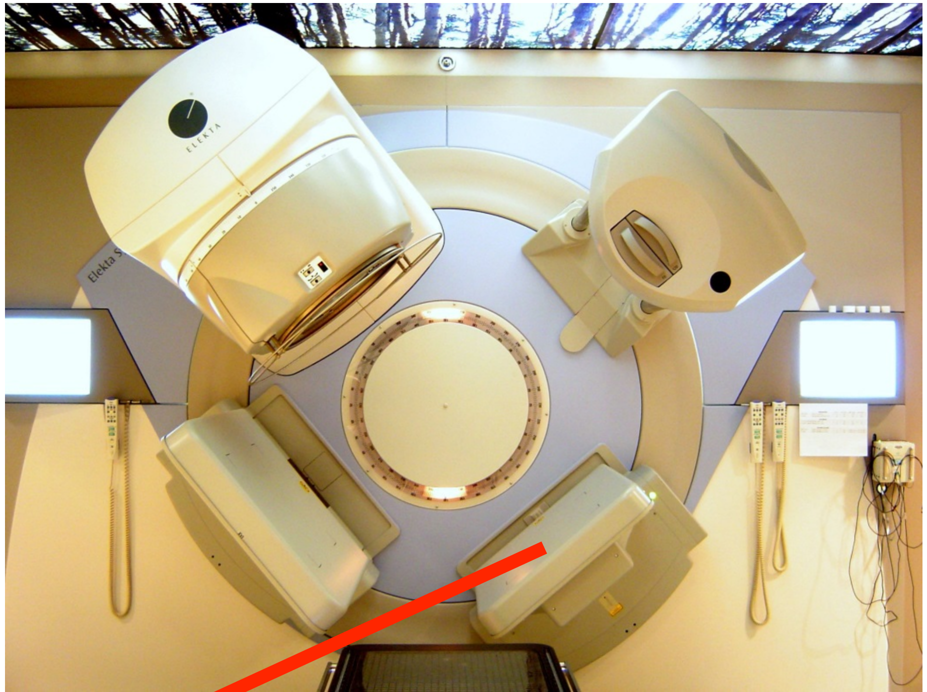
CT Simulators:
AAPM TG66 Recommended (Imaging) QA

Imaging Test	Frequency	Tolerance
CT number accuracy	daily / monthly / annually (less to more comprehensive)	0 ± 5 HU for water
Image noise	daily	manufacturer specs
In plane spatial integrity	daily / monthly	±1mm
Field uniformity	monthly (most common kVp), annually all kVps	within ±5HU
Electron density to CT number conversion	annually & after calibration	consistent with baseline
Spatial resolution	annually	manufacturer specs
Contrast resolution	annually	manufacturer specs

AAPM Report 83, Task Group 66, “Quality assurance for computed-tomography simulators and the computed tomography simulation process” (2003)

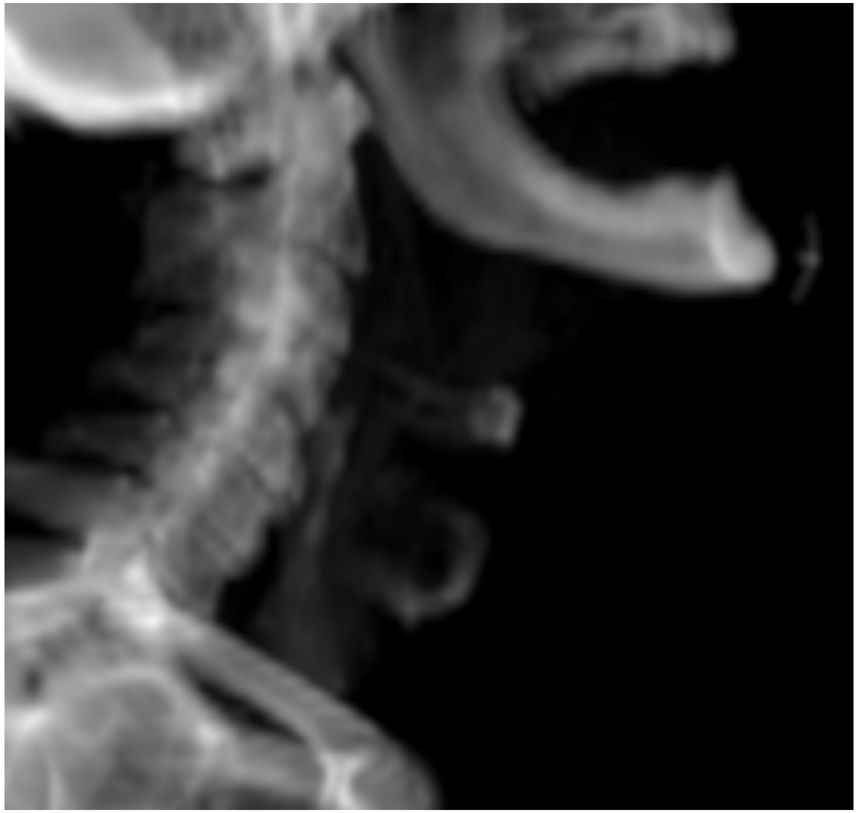
MV Image Guidance:



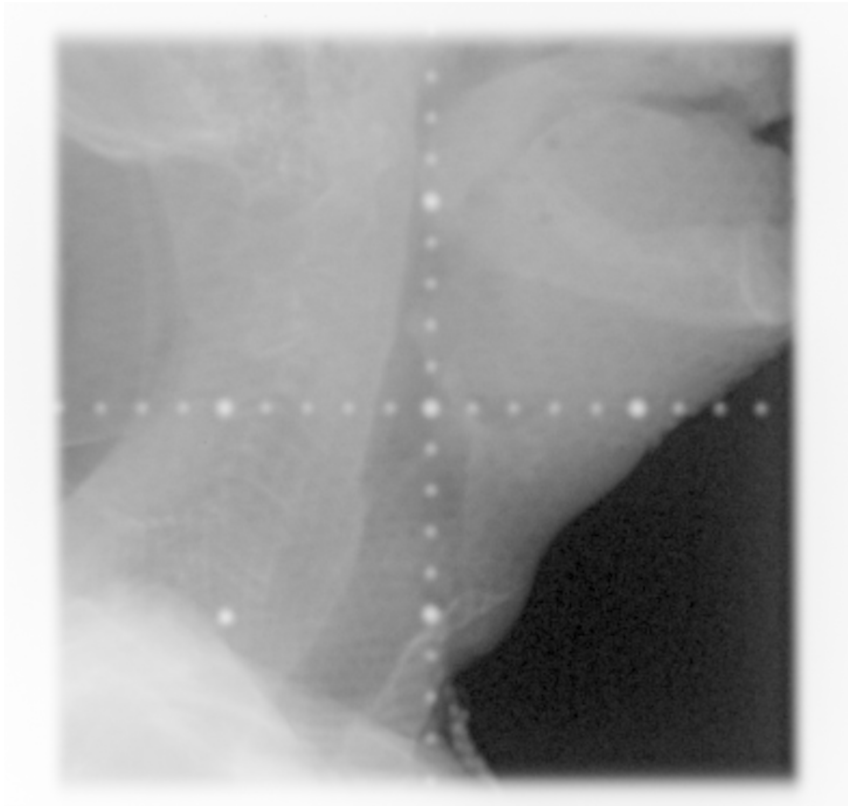
MV (portal) imager

MV Image Guidance: 2D Imaging

Digitally Reconstructed Radiograph (DRR)



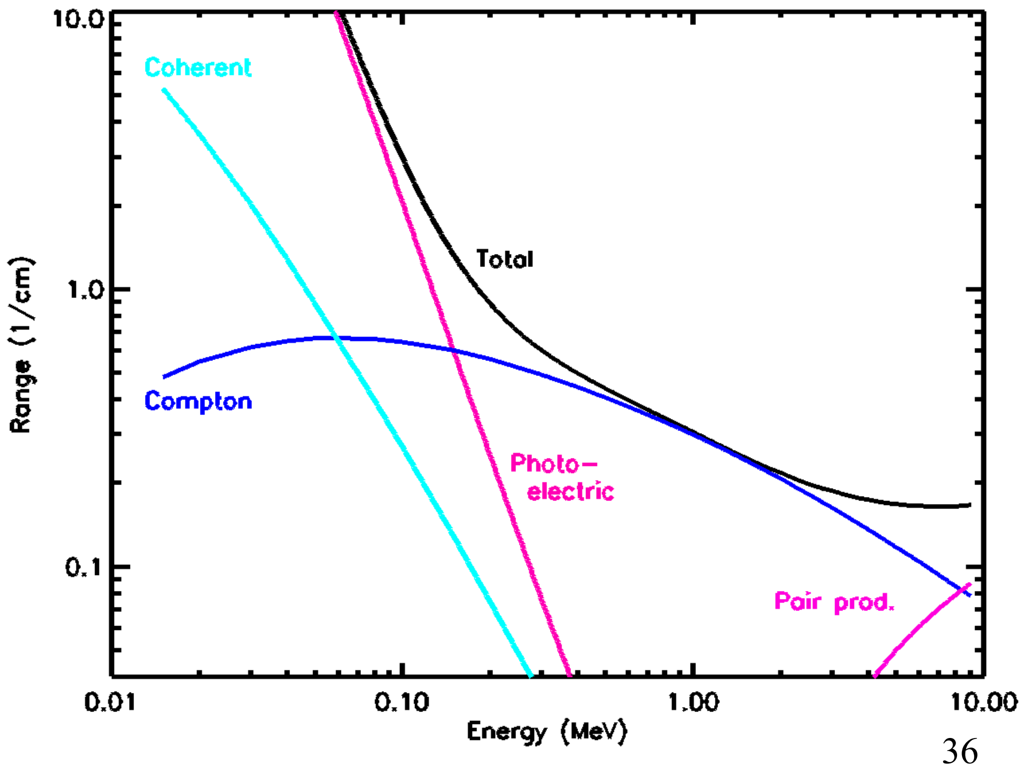
MV Projection Image



MV (Portal) Imaging

Why do megavoltage portal images have such poor contrast compared to diagnostic images?

- Compton effect has weak Z dependence, very little differential absorption
    - diagnostic: photoelectric dominates
    - MV: Compton dominates
- Scattered photons + secondary electrons -> not easily removed
- Large penumbra: geometric + phantom scatter



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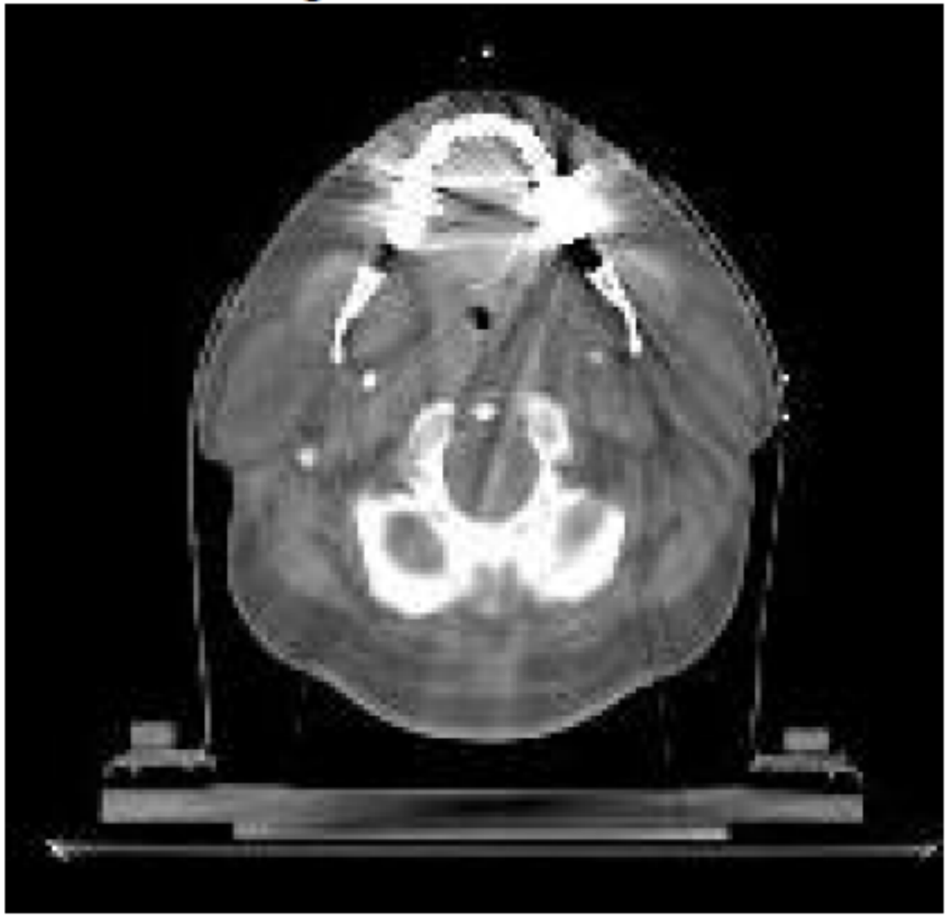
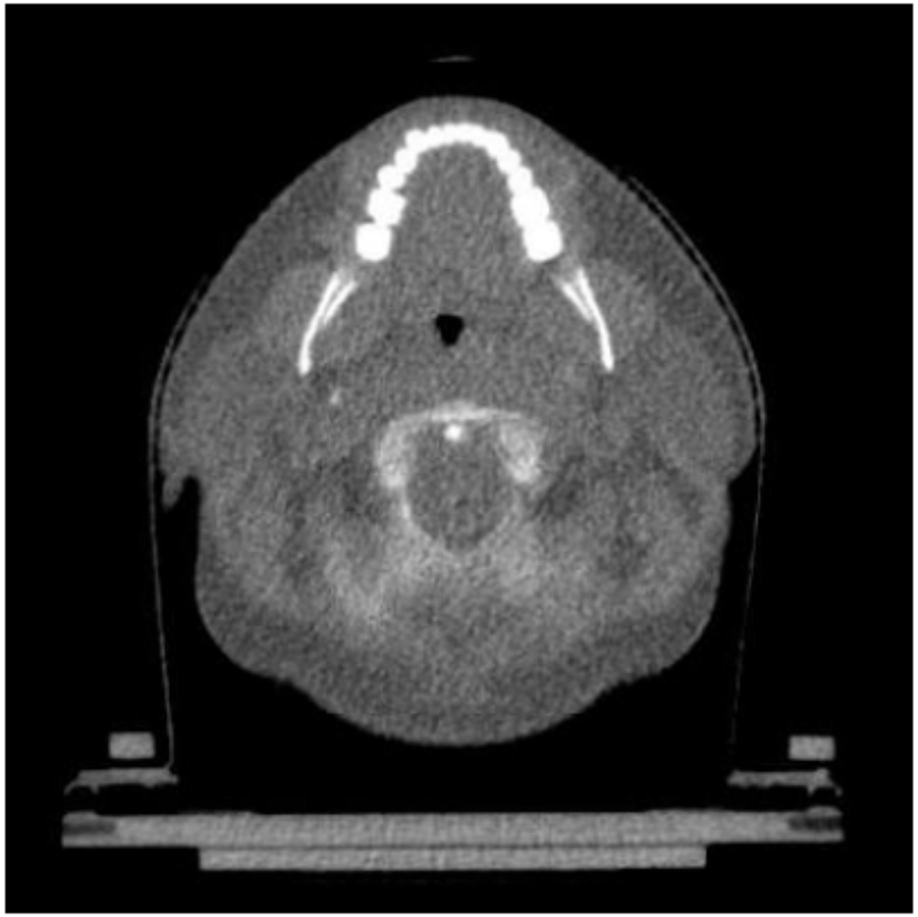
3D MV Imaging: MVCT (Tomotherapy)

Diagnostic KVCT

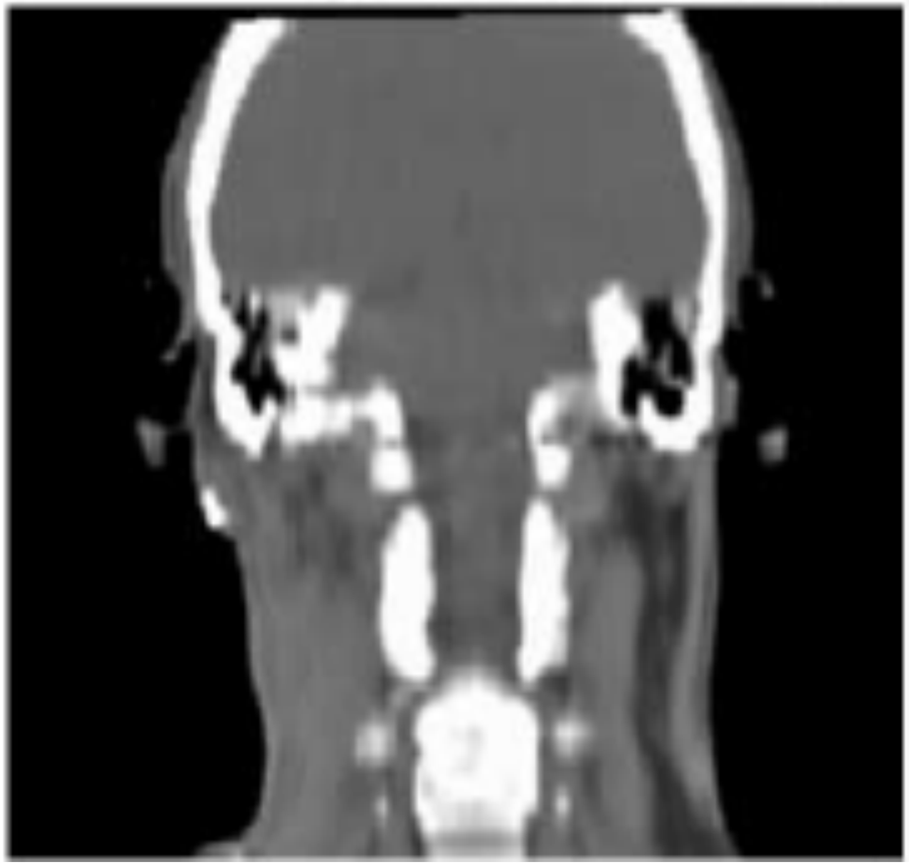


TomoTherapy MVCT

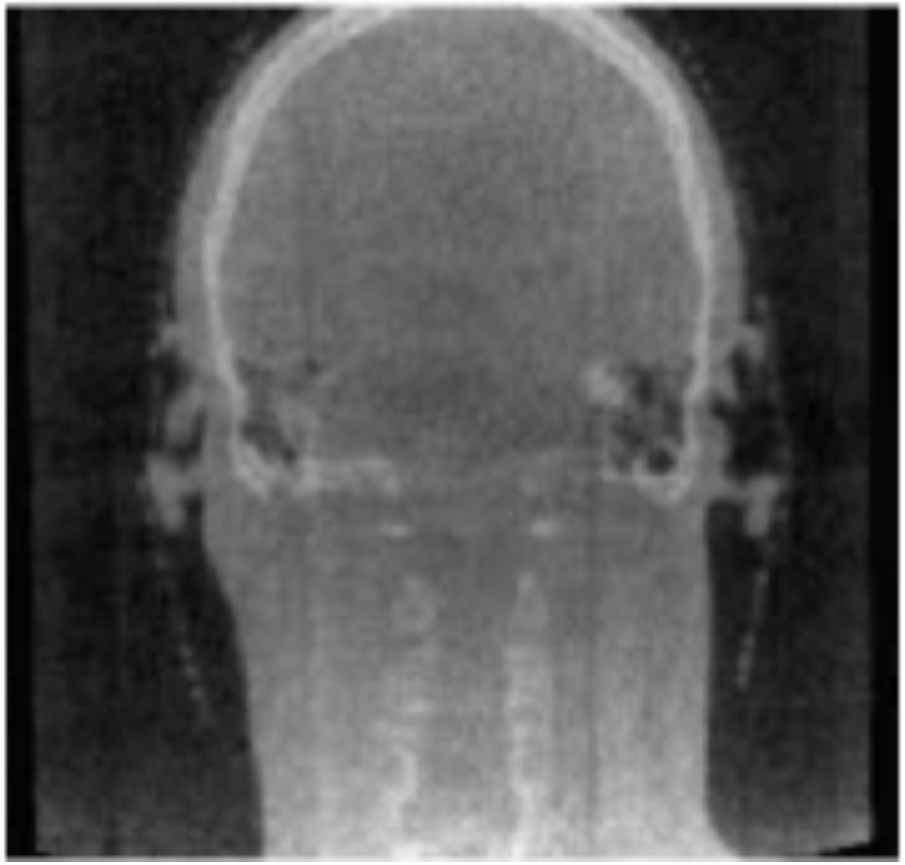


MV CBCT (Linac): kV CT (diagnostic) vs MV CBCT

kV CT (diagnostic)

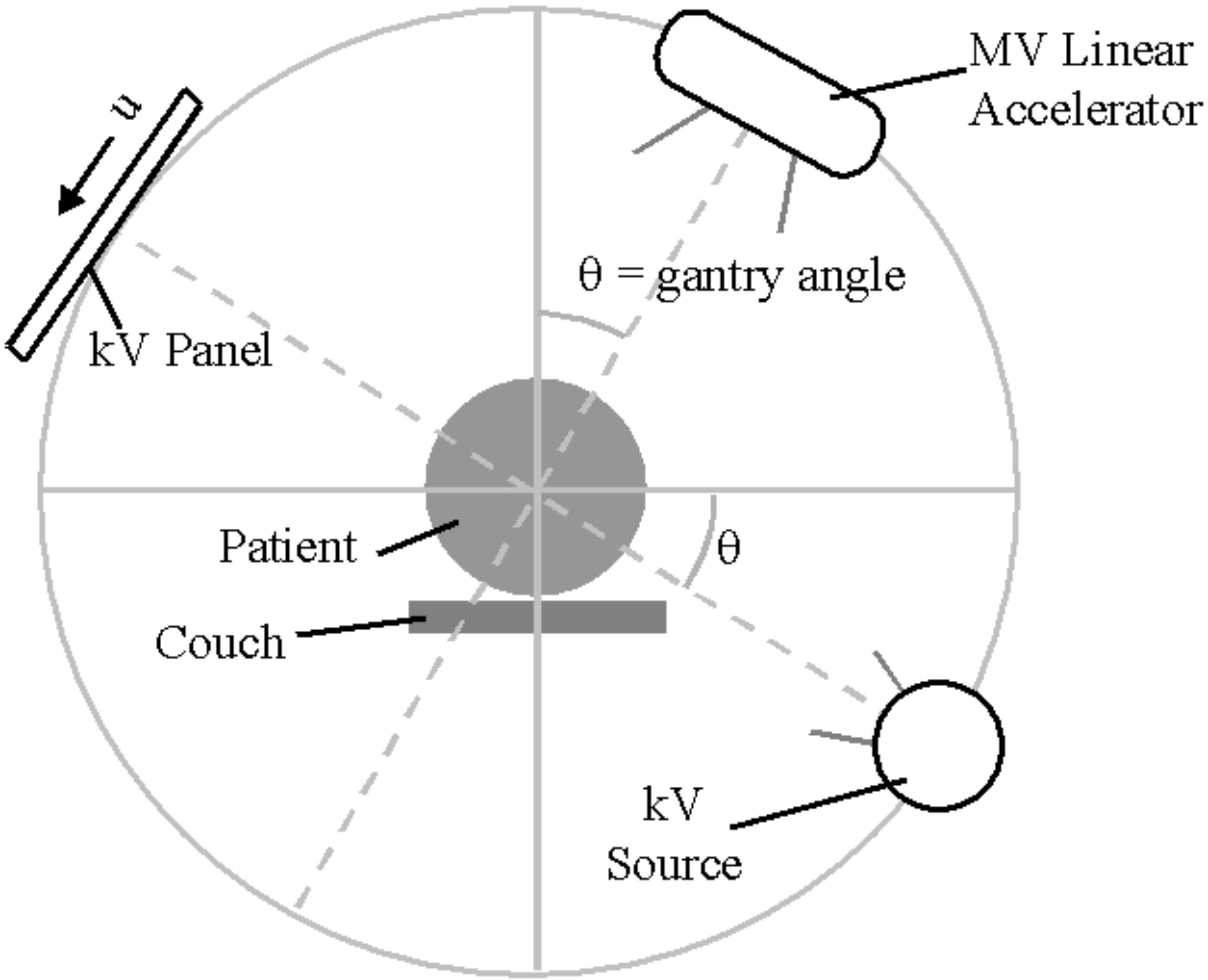


MV CBCT

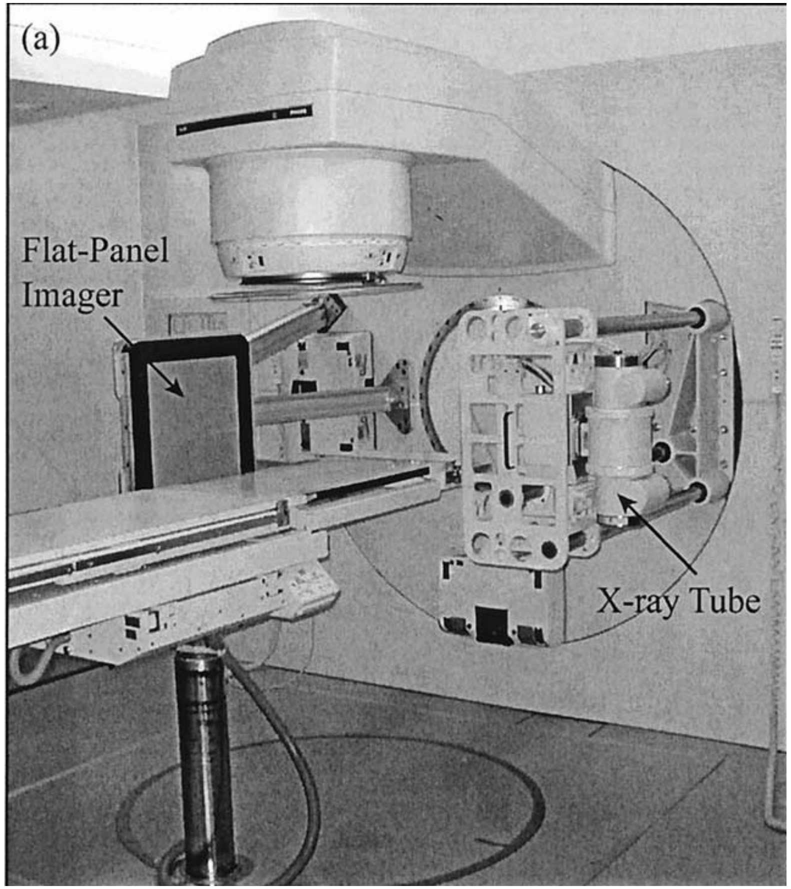


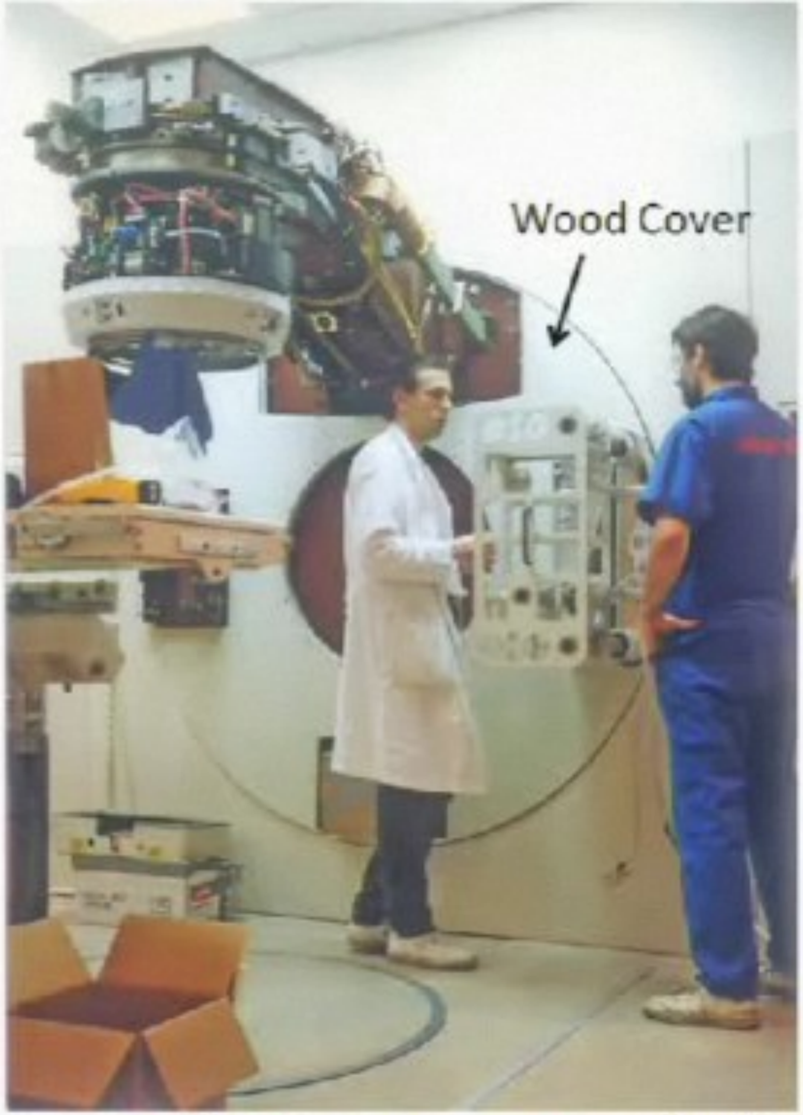
5-15 cGy

kV Image Guidance:



kV Based IGRT



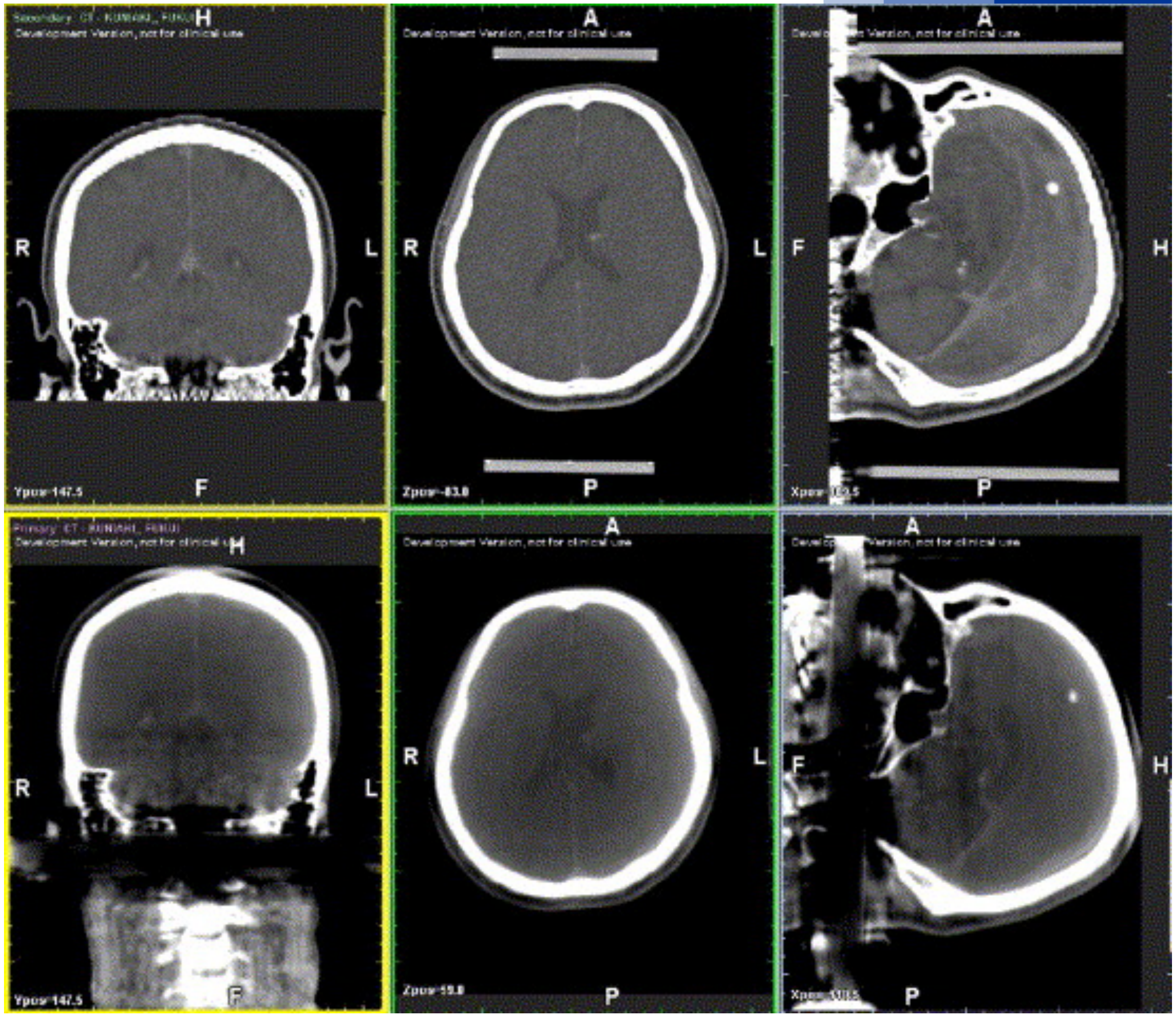


- April – May 1997, Two weekends, one month apart
- Wk 1: Drill holes, move electronics; Wk 2: Mount x-ray source and imager

William Beaumont Hospital, 2002

Conventional CT

CBCT



~2 cGy

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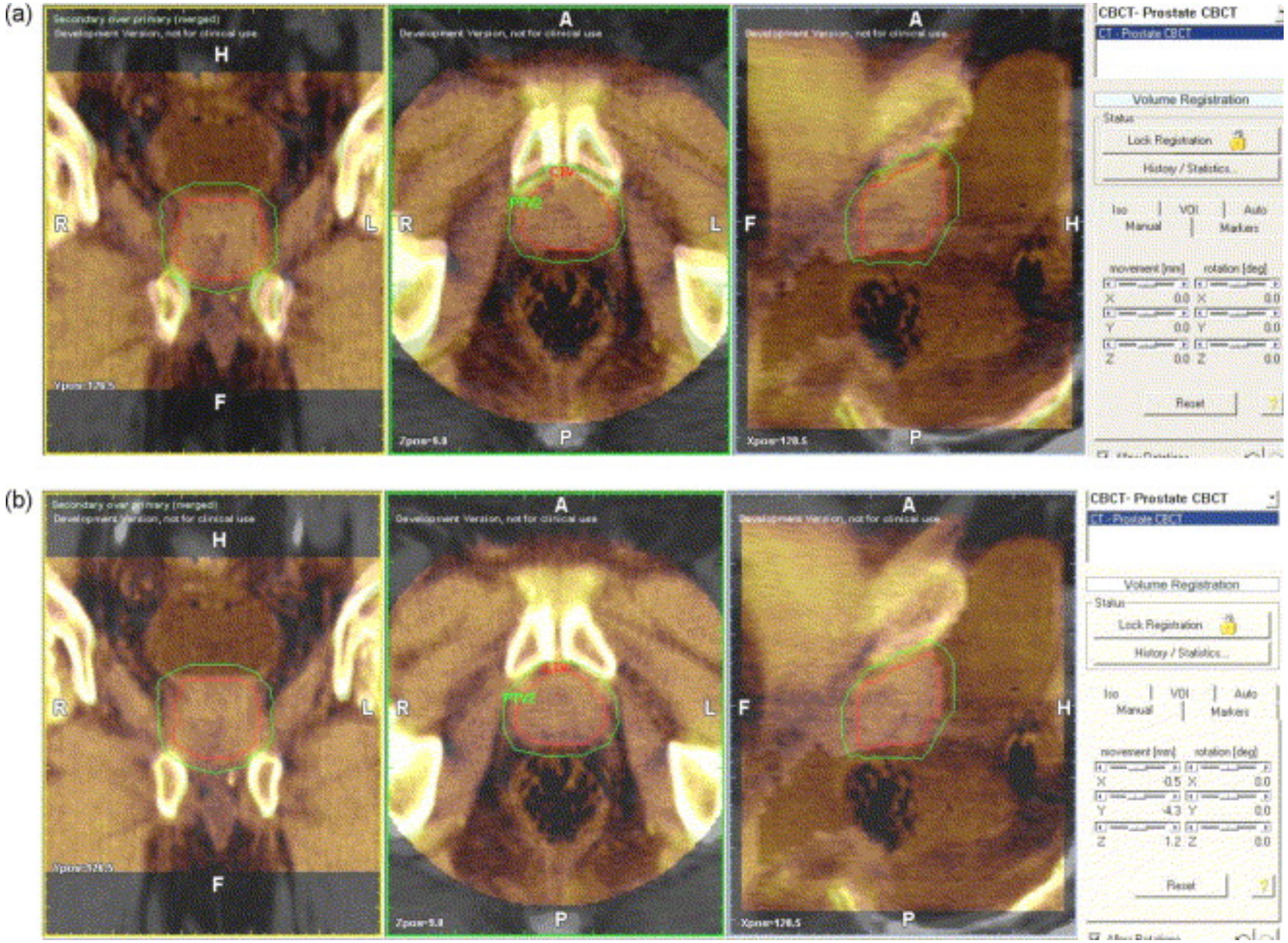
kV Image Guidance:
3D image registration



MV & kV Image Guidance Systems: Reports, Recommendations, & Guidelines

- AAPM:
  - Task Group 142, "Quality assurance of medical accelerators" (2009)
    - http://www.aapm.org/pubs/reports/RPT_142.pdf
  - Task Group 104, "The Role of In-Room kV X-Ray Imaging for Patient Setup and Target Localization" (2009)
    - http://www.aapm.org/pubs/reports/RPT_104.pdf
  - Task Group 179, "QA for IGRT utilizing CT-based technologies" (2012)
    - http://www.aapm.org/pubs/reports/RPT_179.pdf
  - Task Group 58, "Clinical use of electronic portal imaging" (2001)
    - http://www.aapm.org/pubs/reports/RPT_75.pdf
  - Task Group 148, "QA for helical tomotherapy" (2010)
    - http://www.aapm.org/pubs/reports/RPT_148.pdf
  - Task Group 75, "Management of imaging dose during IGRT" (2007)
    - http://www.aapm.org/pubs/reports/RPT_95.pdf
  - Task Group 23, "The measurement, reporting, and management of radiation dose in CT" (2008)
  - Task Group 179, "QA for IGRT utilizing CT-based technologies" (2012)
- Islam *et. al.*, "Patient dose from kV CBCT imaging in radiation therapy" (2006)
  - http://dx.doi.org/10.1118/1.2198169

3D (Tomographic) IGRT:

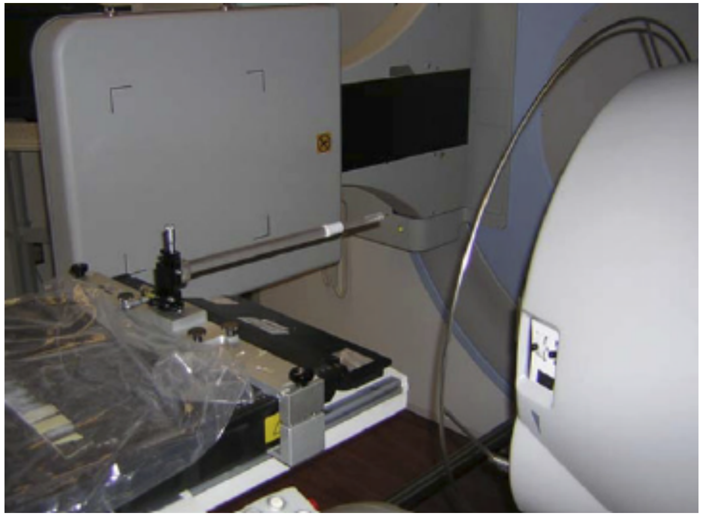
TABLE I. Commercially available CT-based IGRT systems.

Make and model		Elekta XVI	Varian On-Board Imager	Siemens Artiste	TomoTherapy	Siemens Primatom
Imaging configuration		kV-CBCT	kV-CBCT	MV-CBCT	MVCT	kVCT-on rails
Field of view		$50 \times 50 \times 25.6$	$45 \times 45 \times 17$	$40 \times 40 \times 27.4$	40 cm	50 cm
Correction method	Translation	Automatic couch motion	Automatic couch motion	Automatic couch motion	Automatic in 2 directions	Manual couch motion
	Rotation	Optional	None	None	Optional	Optional
Geometric accuracy		Submillimeter	Submillimeter	Submillimeter	Submillimeter	Submillimeter
Dose (cGy)		0.1–3.5	0.2–2.0	3–10	0.7–3.0	0.05–1
Image acquisition and reconstruction time		2 min	1.5 min	1.5 min	5 s per slice	3 s per sec

Med. Phys. 39 (4), April 2012

3D IGRT Geometric Calibration

geometric calibration of kV x-ray imaging system relative to MV



"flexing" of detector is corrected as a function of gantry angle

B)

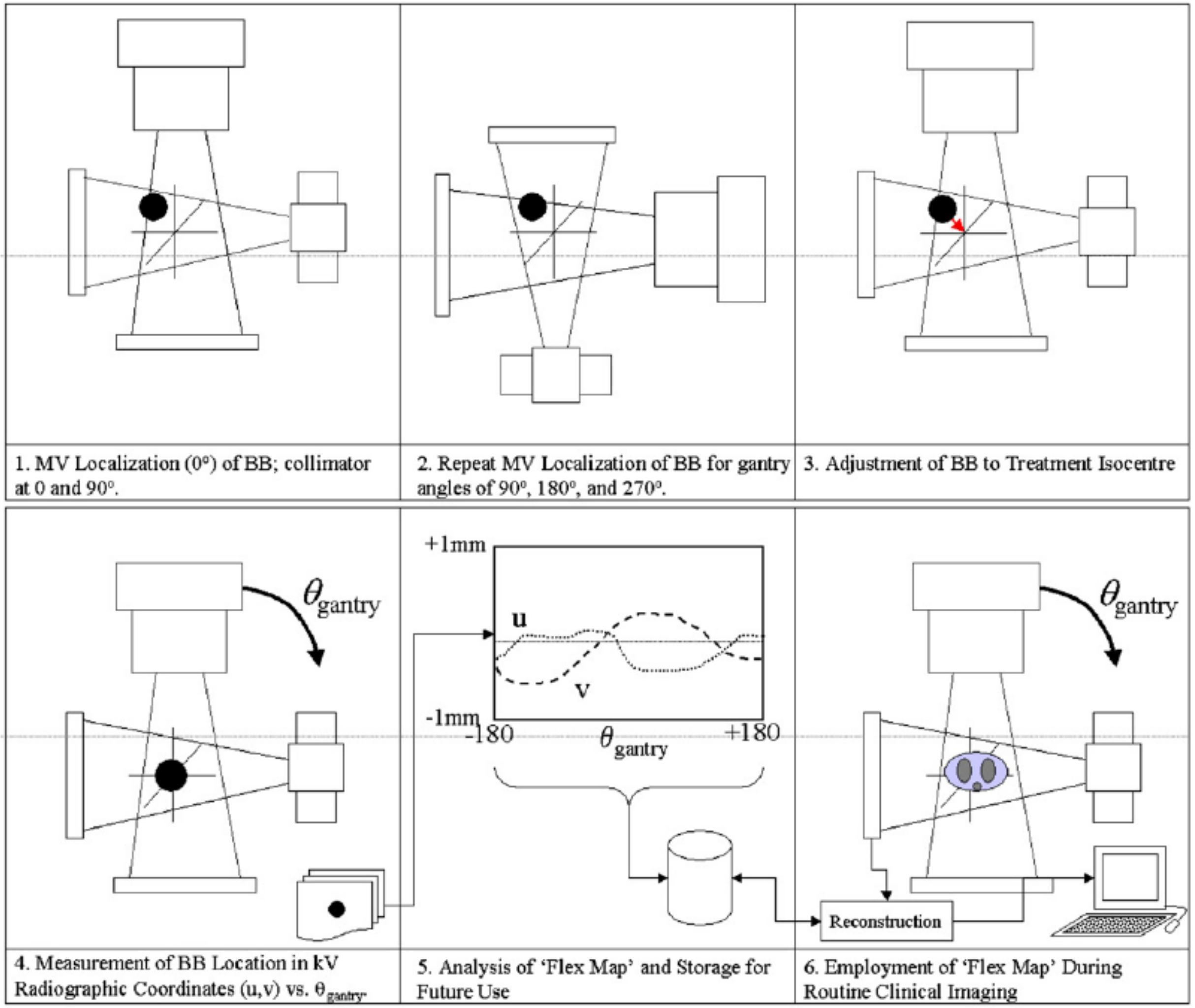


Fig. 1. (A) Apparatus used for the geometric calibration of the volumetric imaging system. (B) In the megavoltage stage, the position of the ball-bearing with respect to the treatment beam isocenter is assessed from portal image analysis. For the synergy system, the reconstruction software digitally corrects for the flex motions. For the OBI system, flex motions are compensated for by servos in the robotic arm.

Int. J. Radiation Oncology Biol. Phys., Vol. 71, No. 1, Supplement, pp. S57–S61, 2008

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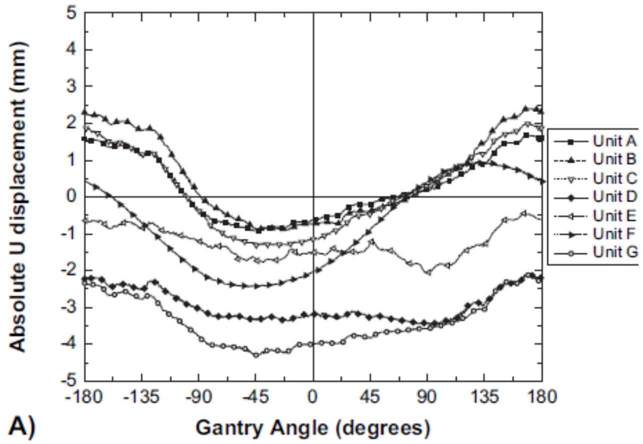
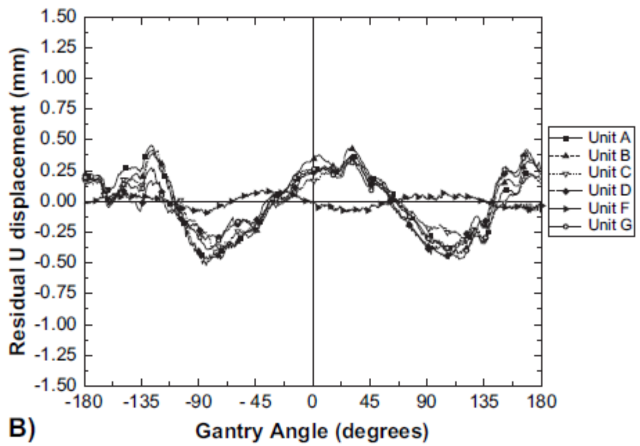
3D IGRT Geometric Calibration

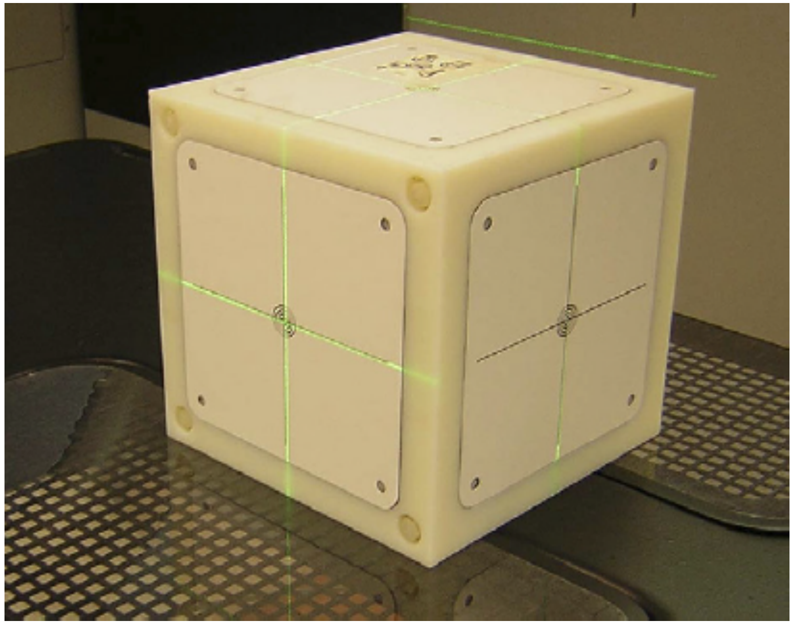
absolute flex



residual flex
~0.25mm



daily check of geometric accuracy



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Int. J. Radiation Oncology Biol. Phys., Vol. 71, No. 1, Supplement, pp. S57–S61, 2008

Imaging Panel Calibration

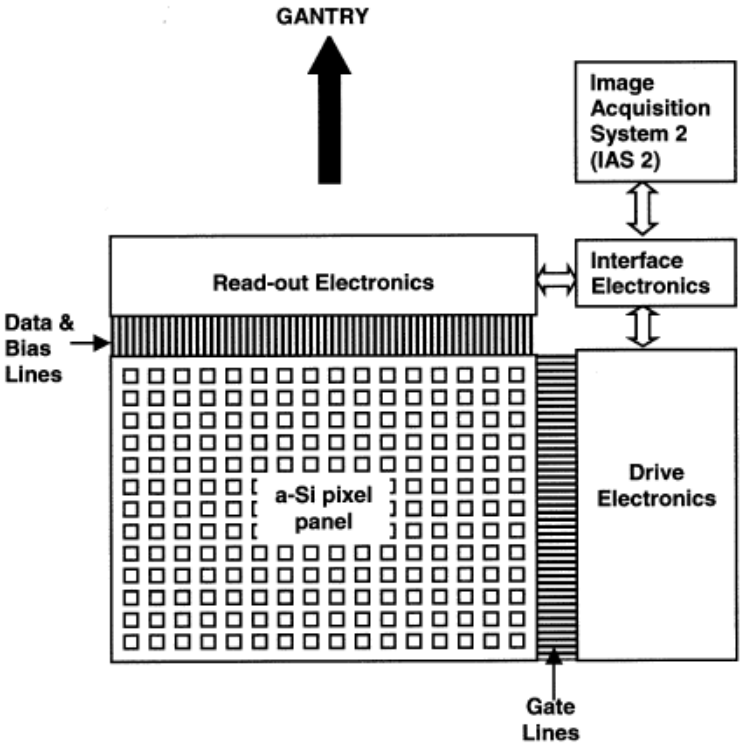


Fig. 1. Schematic drawing of the image detection unit (IDU) in the a-Si EPID.[5]

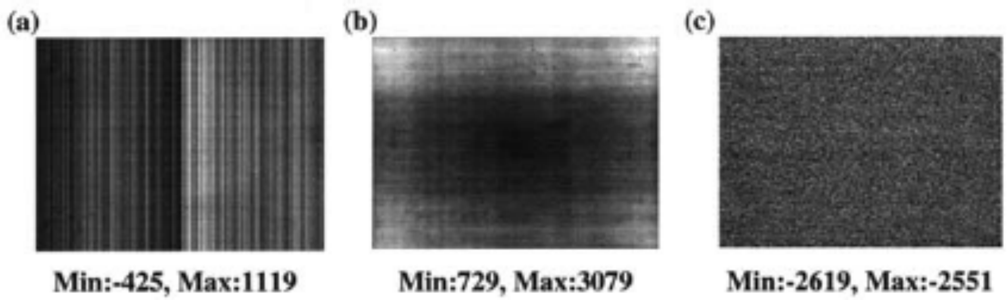


Fig. 2. Images of a (a) dark field, (b) flood field, and (c) test image taken using the 6-MV, 300 MU/min, standard scan acquisition mode. The minimum and maximum pixel values in each image are reported.

DukeMedicine

Medical Dosimetry, Vol. 29, No. 1, pp. 11−17, 2004

3D CBCT:
panel shift to achieve larger field of view

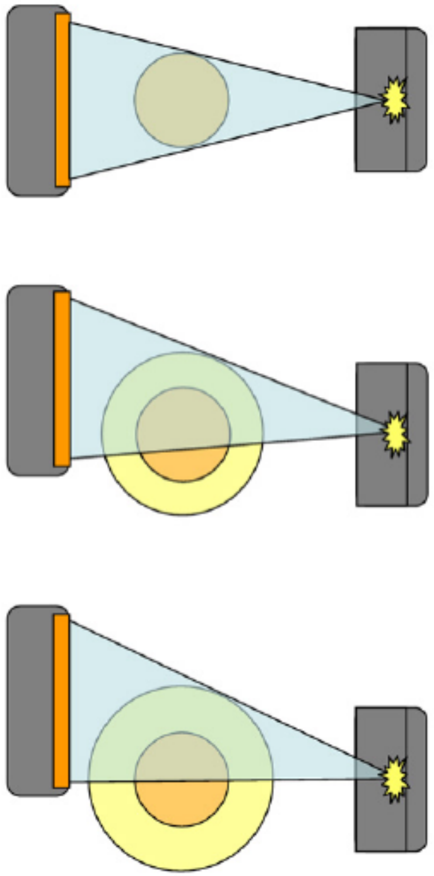


FIG. 3. Illustration of the various settings for the width of the field of view in the kilovoltage imaging system. In the "S" setting, the kilovoltage panel is centrally aligned with the tube and the field of view of 27.67 cm (at isocenter) is centered in the middle of the patient. For the "M" and "L" settings, the panel is moved up by 11.5 cm and 19 cm respectively, resulting in partial scans and allowing larger patient diameters to be scanned.

Journal of Applied Clinical Medical Physics, Vol. 8, No. 3, Summer 2007

3D CBCT: Bowtie Filter(s)

half fan

full fan

kV/MV Image Guidance Routine QA:

Planar (2D) Imaging:

- Collision interlocks
- Positioning / Repositioning
- Imaging & Treatment Coordinate Coincidence
- Scaling
- Spatial Resolution
- Contrast
- Uniformity & Noise
- Imaging Dose
- Beam quality / energy (kV)

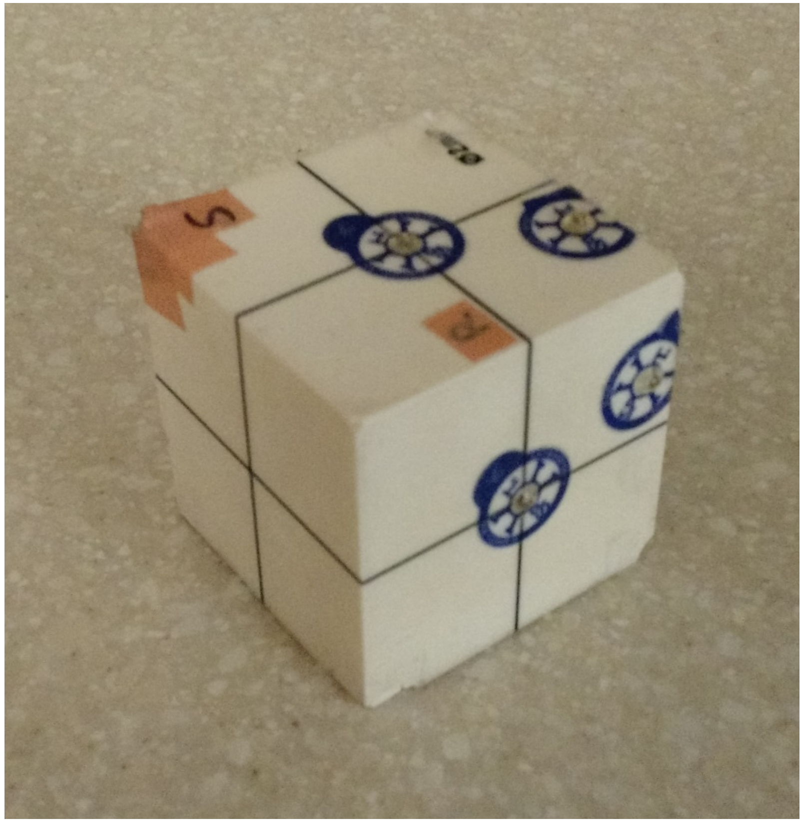
3D Imaging

- Collision interlocks
- Positioning / Repositioning
- Imaging & Treatment Coordinate Coincidence
- Geometric Distortion
- Spatial Resolution
- Contrast
- HU Constancy
- Uniformity & Noise
- Imaging Dose

AAPM Task Group 142, "Quality Assurance of Medical Accelerators" (2009)

kV/MV Image Guidance QA: Positioning / Repositioning

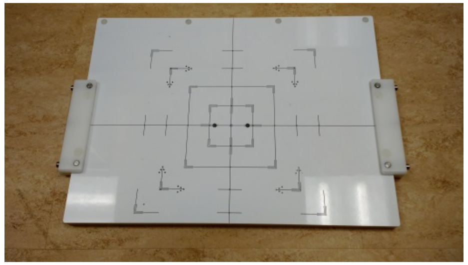
- More important than image quality in IGRT setting!
- Basic functionality test for image guidance
  - setup phantom
  - image
  - shift based on imaging
  - verify shift



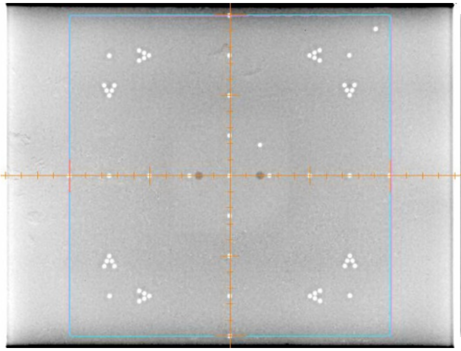
kV/MV Image Guidance QA:
Imaging & Treatment Coordinate Coincidence

- Each imaging system has its own coordinate system
- Correlation with delivery coordinate system through a calibration process
- Example: verify kV isocenter coincidence with MV isocenter
  - image same setup with MV & kV

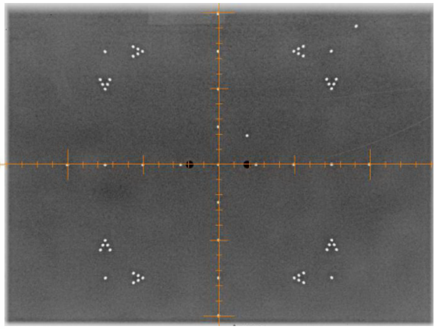
device for 2D imaging:



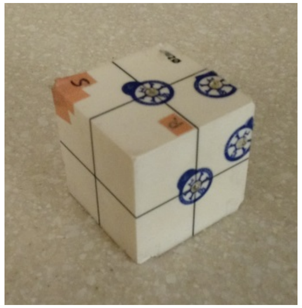
MV image:



kV image:



device for 3D imaging:



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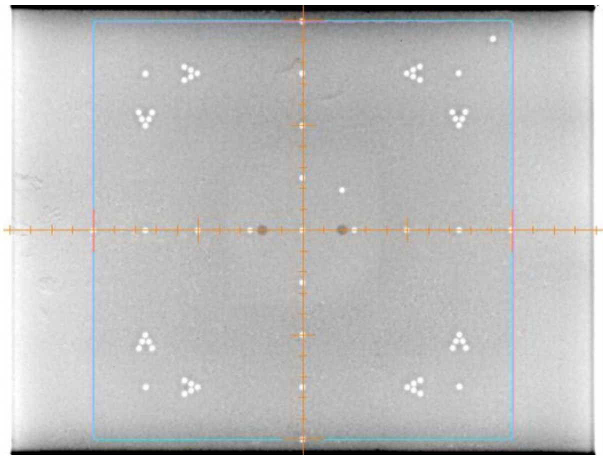
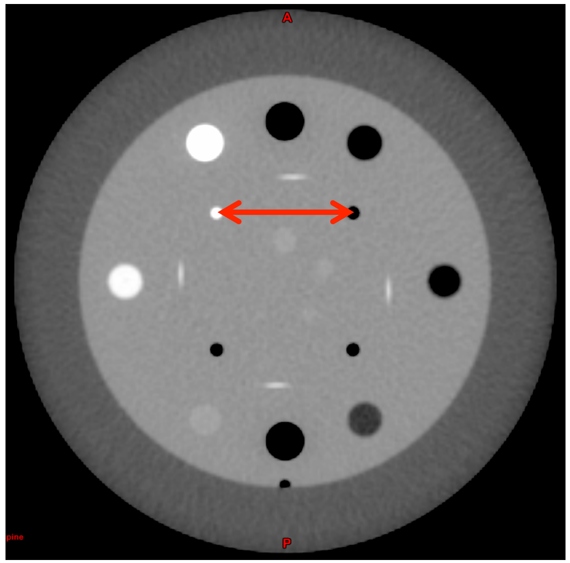
Scaling

- Ensure accurate image scaling
- Performed by using imaging software to measure known distances in each axis
- For 2D: distance from source is important due to magnification

2D

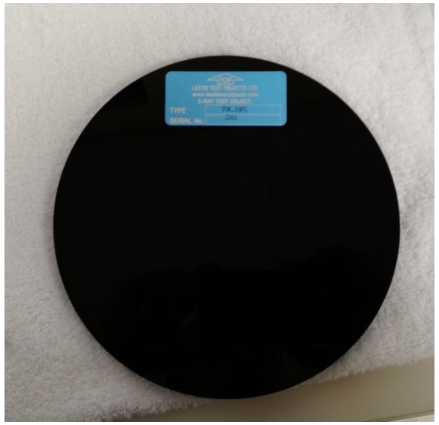


3D

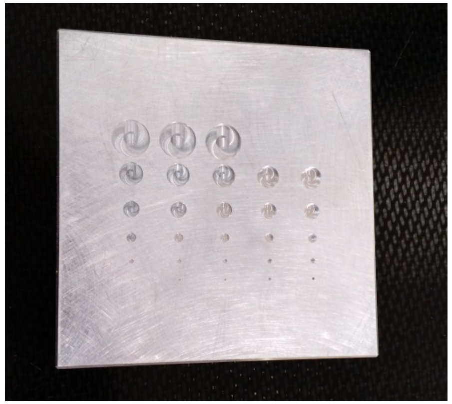


2D IGRT QA:
Contrast & Spatial Resolution

kV phantom:

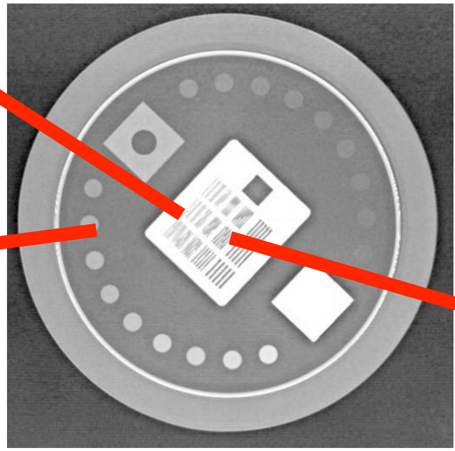


MV phantom:

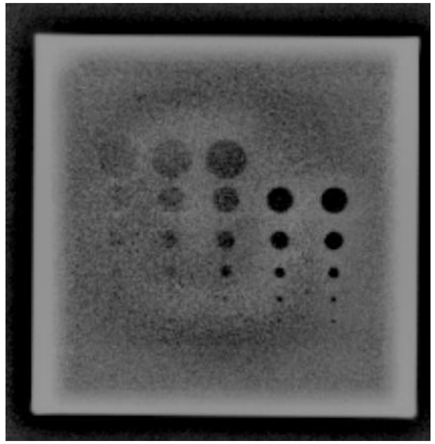


spatial resolution

contrast resolution

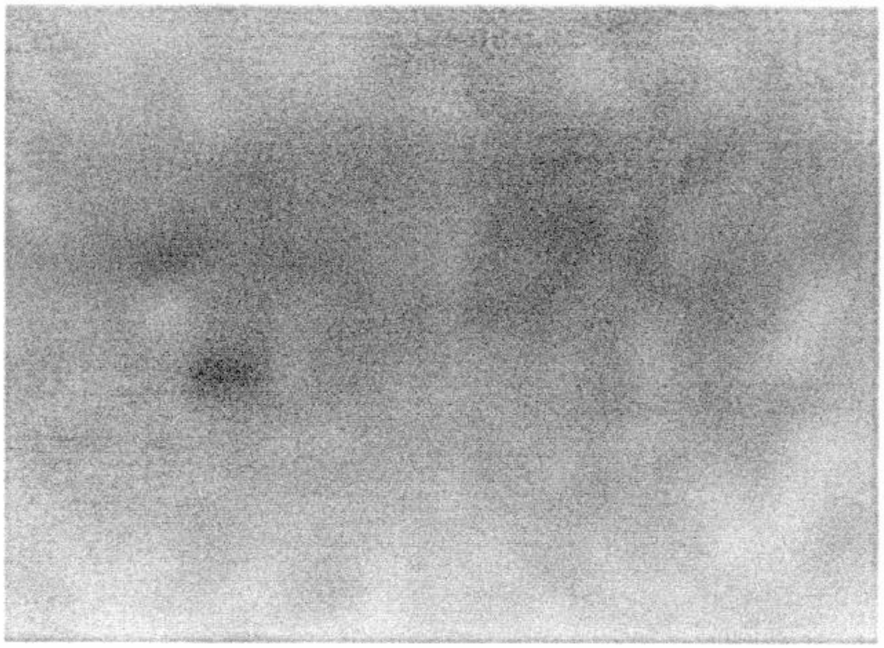


orientation of phantom relative to detector array matters!

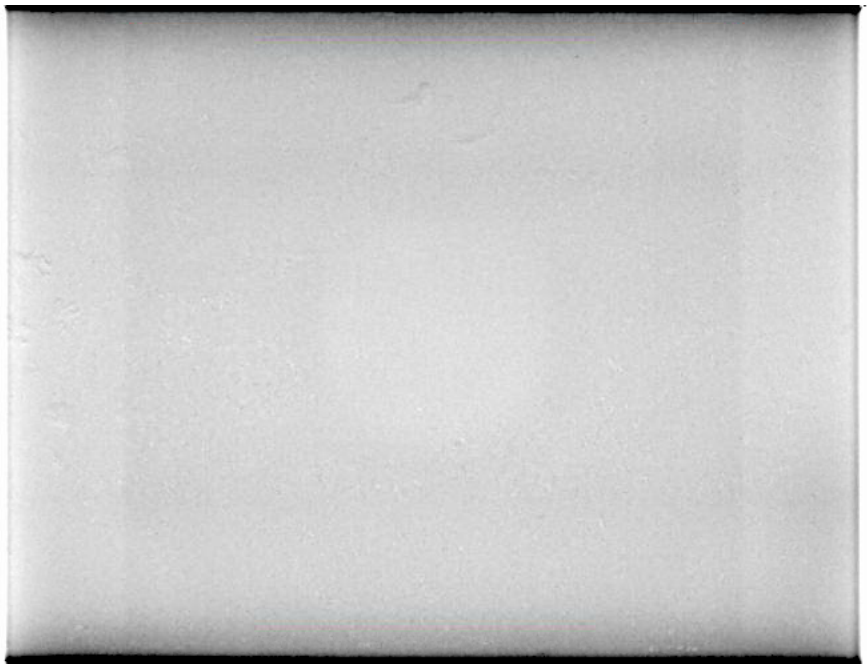


2D IGRT QA:
Uniformity & Noise

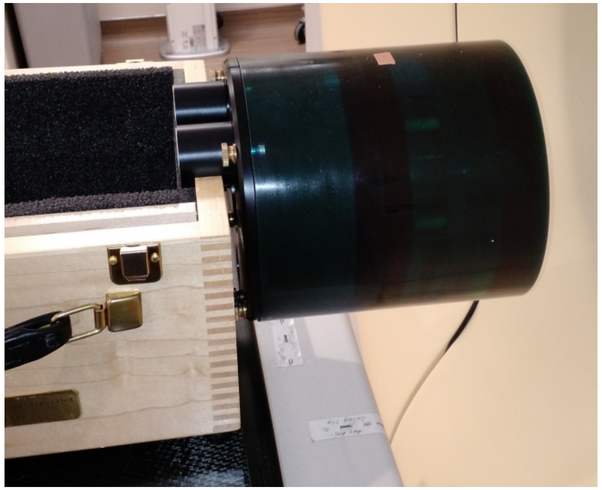
kV uniformity



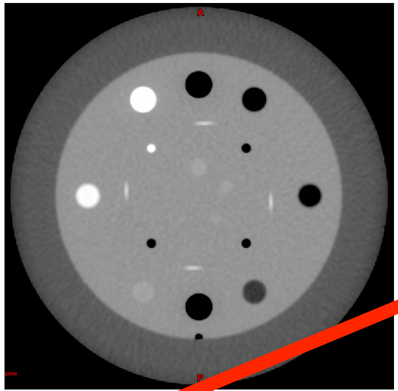
MV uniformity



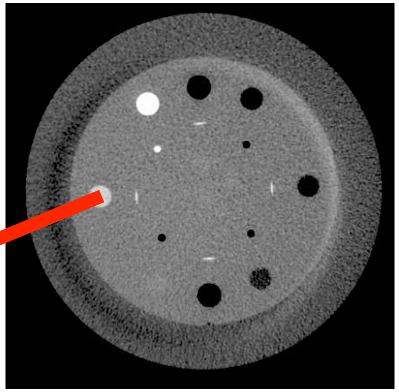
3D IGRT Image Quality Tests: Similar to diagnostic CT



CT# accuracy: diagnostic CT



CT# accuracy: kV CBCT



CT#s are relative for CBCT due to large proportion of scatter in projection images

Often CT#s are calibrated using a phantom scan to match the expected values.

Accurate CT# in phantom may not translate to accurate CT#s in a patient!

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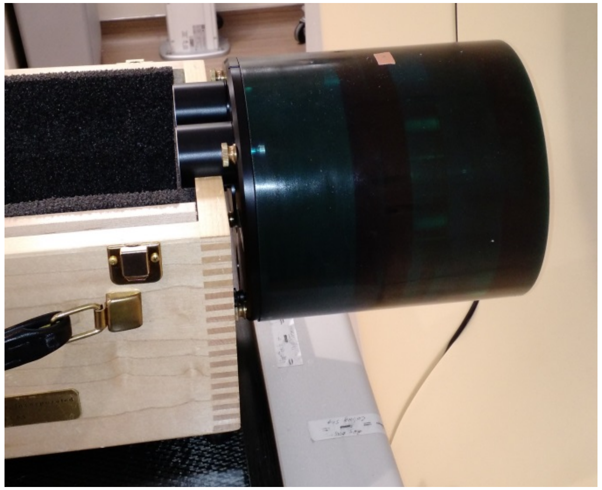
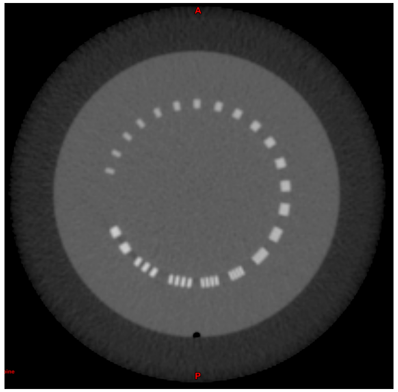
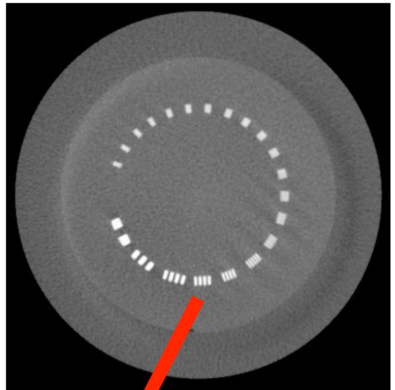
3D IGRT Image Quality Tests: Similar to diagnostic CT



high contrast resolution:
diagnostic CT

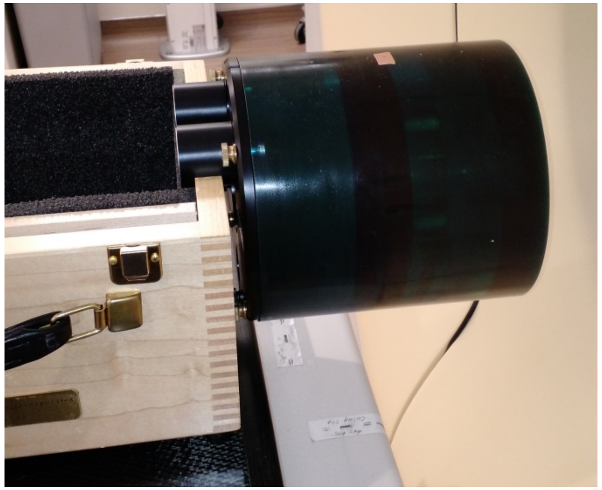


high contrast resolution:
kV CBCT

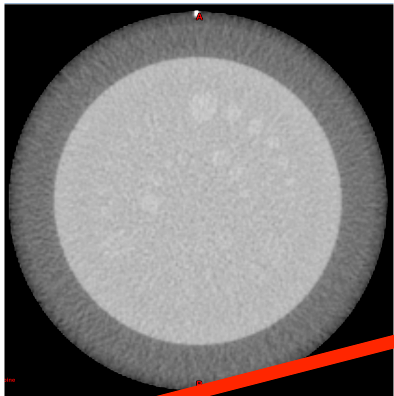


high contrast resolution will be dependent on the imaging protocol

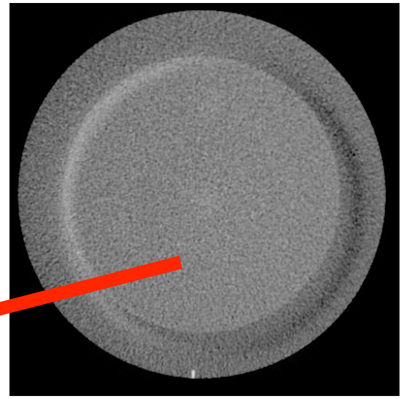
3D IGRT Image Quality Tests: Similar to diagnostic CT



low contrast resolution
diagnostic CT

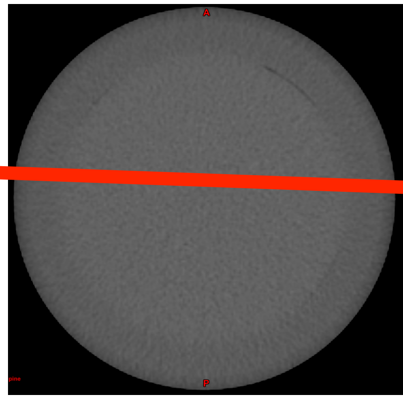


low contrast resolution
kV CBCT

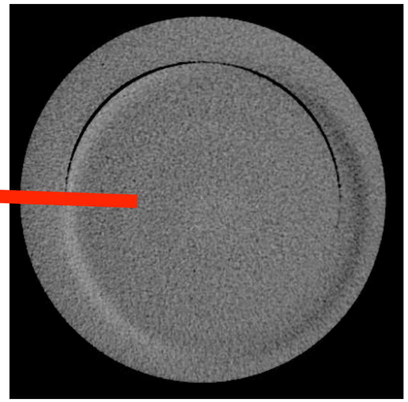


poorer low contrast resolution for CBCT (expected)

uniformity & noise
diagnostic CT



uniformity & noise
kV CBCT



CT#s monitored relative to a baseline (due to expected differences from truth)

MV IGRT Imaging Dose:

- Imaging is done with the treatment beam hence dose can be directly calculated using treatment planning system / hand calculation
- Exception: some linear accelerators have a lower energy (1MV / 2.5MV) used only for imaging

kV IGRT Imaging Dose & Beam Quality

- 2D: many meters are available to measure kVp, HVL, exposure to skin, etc.

- 3D:
  - Farmer chamber in cylindrical phantom (CTDI phantom)
  - N_k calibration factor

kV/MV Image Guidance: Recommendations for Daily QA

TABLE VI. Imaging.

Procedure	Application-type tolerance: non-SRS/SBRT	Application-type tolerance: SRS/SBRT
Daily[a]		
Planar kV and MV (EPID) imaging		
Collision interlocks	Functional	Functional
Positioning/repositioning	≤2 mm	≤1 mm
Imaging and treatment coordinate coincidence (single gantry angle)	≤2 mm	≤1 mm
Cone-beam CT (kV and MV)		
Collision interlocks	Functional	Functional
Imaging and treatment coordinate coincidence	≤2 mm	≤1 mm
Positioning/repositioning	≤1 mm	≤1 mm

daily: functionality & geometric accuracy

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kV/MV Image Guidance: Recommendations for Monthly QA

Table VI. Imaging.

Procedure	Application-type tolerance: non-SRS/SBRT	SRS/SBRT
Monthly		
Planar MV imaging (EPID)		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling[b]	≤2 mm	≤2 mm
Spatial resolution	Baseline[c]	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Planar kV imaging[d]		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Cone-beam CT (kV and MV)		
Geometric distortion	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
HU constancy	Baseline	Baseline
Uniformity and noise	Baseline	Baseline

monthly: geometric
+ image quality

kV/MV Image Guidance: Recommendations for Annual QA

TABLE VI. Imaging.

Procedure	Application-type tolerance non-SRS/SBRT	SRS/SBRT
Annual (A)		
Planar MV imaging (EPID)		
Full range of travel SDD	±5 mm	±5 mm
Imaging dose[e]	Baseline	Baseline
Planar kV imaging		
Beam quality/energy	Baseline	Baseline
Imaging dose	Baseline	Baseline
Cone-beam CT (kV and MV)		
Imaging dose	Baseline	Baseline

annual: geometry, imaging dose, beam quality

Recommended QA & Tolerances

TABLE II. Summary of QC tests recommended for CT-based IGRT systems. Tolerances may change according to expectations, experience and performance.

Frequency	Quality metric	Quality check	Tolerance
Daily	Safety	Collision and other interlocks	Functional
		Warning lights	Functional
	System operation and accuracy	Laser/image/treatment isocentre coincidence OR	±2 mm
		Phantom localization and repositioning with couch shift	±2 mm
Monthly or upon upgrade	Geometric	Geometric calibration maps[a] OR	Replace/refresh
		kV/MV/laser alignment	±1 mm
		Couch shifts: accuracy of motions	±1 mm
	Image quality	Scale, distance, and orientation accuracy[a]	Baseline
		Uniformity, noise[a]	Baseline
		High contrast spatial resolution[a]	≤ 2 mm (or ≤ 5 lp/cm)
		Low contrast detectability[a]	Baseline
If used for dose calculation	Image quality	CT number accuracy and stability[a]	Baseline
Annual	Dose	Imaging dose	Baseline
	Imaging system performance	X-ray generator performance (kV systems only): tube potential, mA, ms accuracy, and linearity	Baseline
	Geometric	Anteroposterior, mediolateral, and craniocaudal orientations are maintained (upon upgrade from CT to IGRT system)	Accurate
	System operation	Long and short term planning of resources (disk space, manpower, etc.)	Support clinical use and current imaging policies and procedures

[a]These tests can be performed on a semiannual basis after stability has been demonstrated, 6–12 months after commissioning.

Patient Support Systems:

QA

- Geometric:
  - accuracy of table index, & patient re-positioning
  - accuracy of couch angle
  - pitch & roll accuracy (for 6-degree capable tables)
- Dosimetric:
  - increased skin dose
  - reduced tumor dose
  - altered dose distribution

Weight Limits:

	Weight Limit (Lbs)	Bore Diameter (cm)	Image FOV (cm)
Exact couch	500		
Truebeam	500 (440 end)		
Brainlab Robotic Couch	275		
Brainlab Non-Robotic	350		
TrueBeam STX (Perfect Pitch)	440		
Linac (CBCT)	440		45 or 25 (~ 15 in S/I)
Simulator	600		
CT Simulator (GE OptimaCT580RT)	500	80	65
CT Simulator (Siemens)	660	78	50 (78 ext. recon)
PET/CT Simulator (Siemens)	500	78	50 (78 ext. recon)
CT Simulator (Phillips)	650	85	60 (70 ext. recon)
MR (GE)	350	60	48
MRI (GE OptimaMR45W)	500	70	50

Know your machine limits, & keep available for reference

Couchtop Dosimetric Considerations: Increased Skin Dose

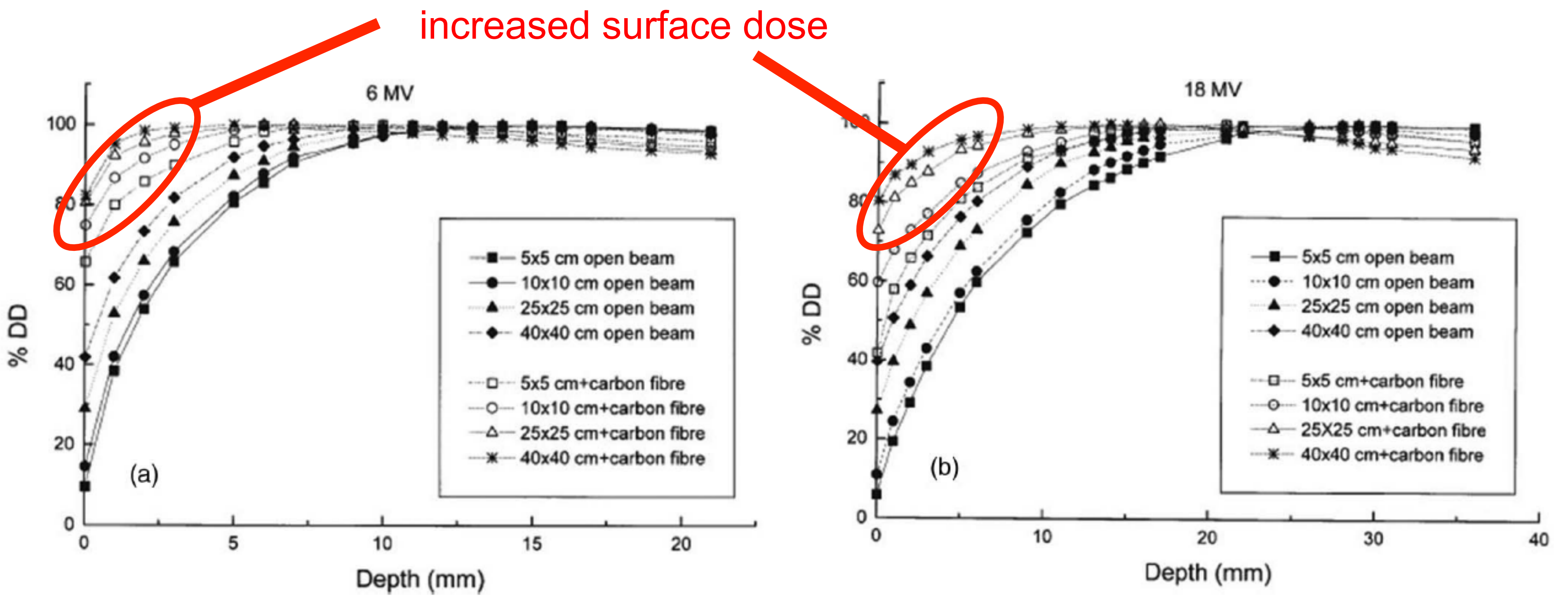
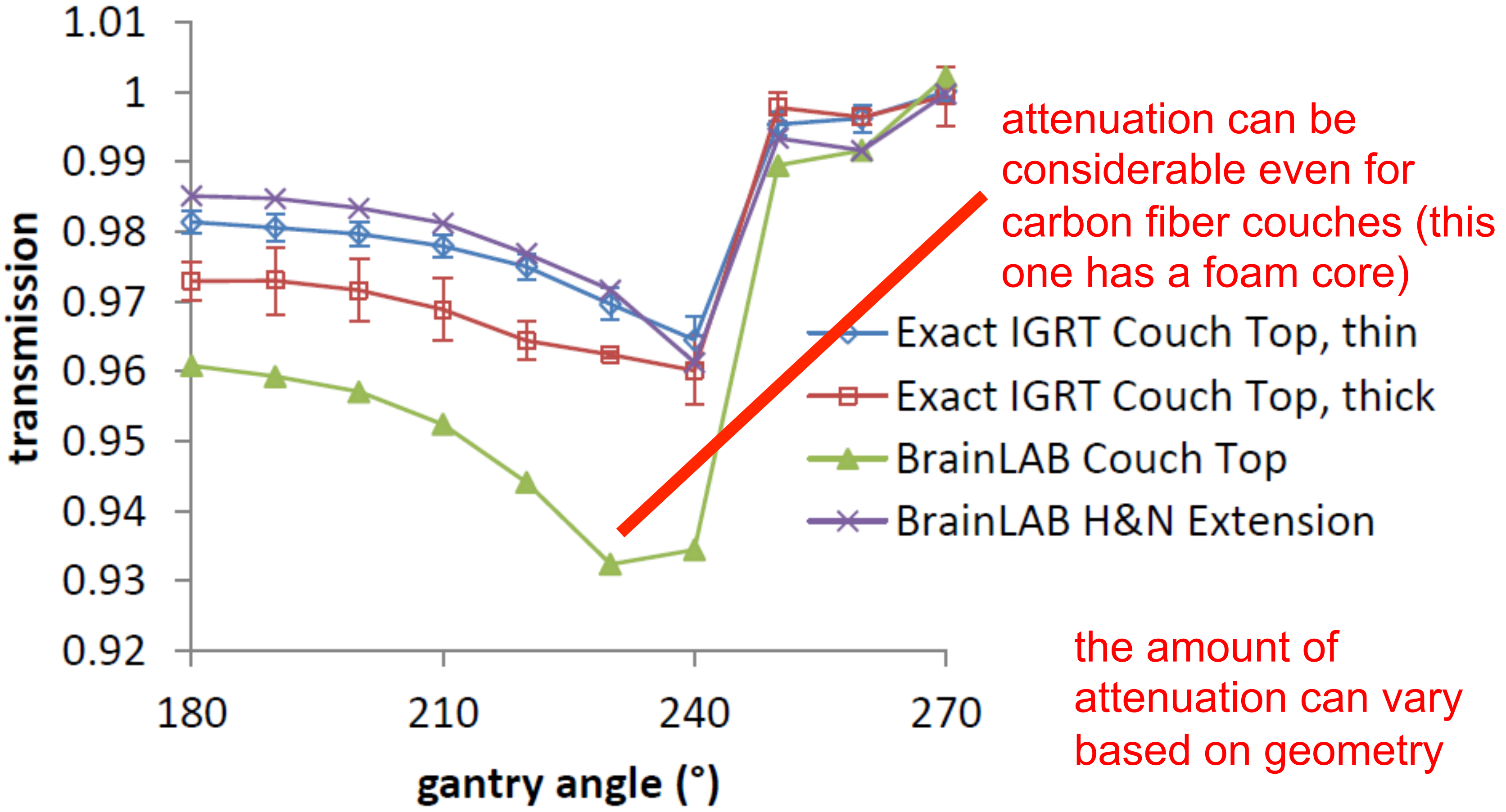


FIG. 3. PDD for 6 MV and 18 MV for different field sizes with and without couch top. From Meydanci and Kemikler, "Effect of a carbon fiber tabletop on the surface dose and attenuation for high-energy photon beams," Radiat. Med. **26**, 539–544 (2008).

DukeMedicine

AAPM Task Group 176, "Dosimetric effects caused by couch tops and immobilization devices" (2014)

Couchtop Dosimetric Considerations: Attenuation (at Depth)



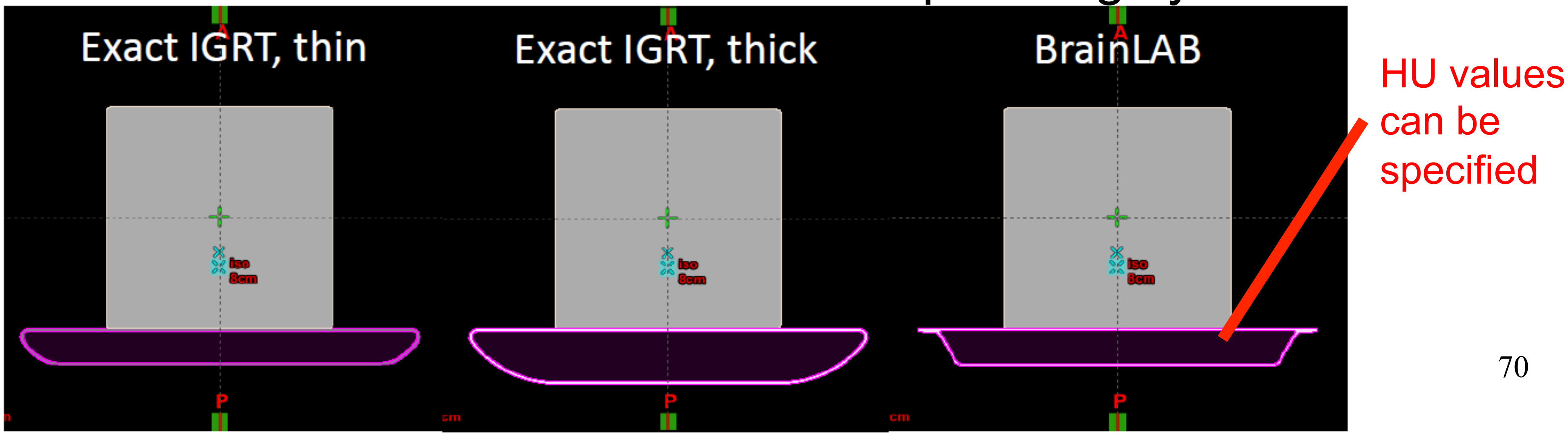
attenuation can be considerable even for carbon fiber couches (this one has a foam core)

the amount of attenuation can vary based on geometry

Patient Support Systems: Couch Attenuation

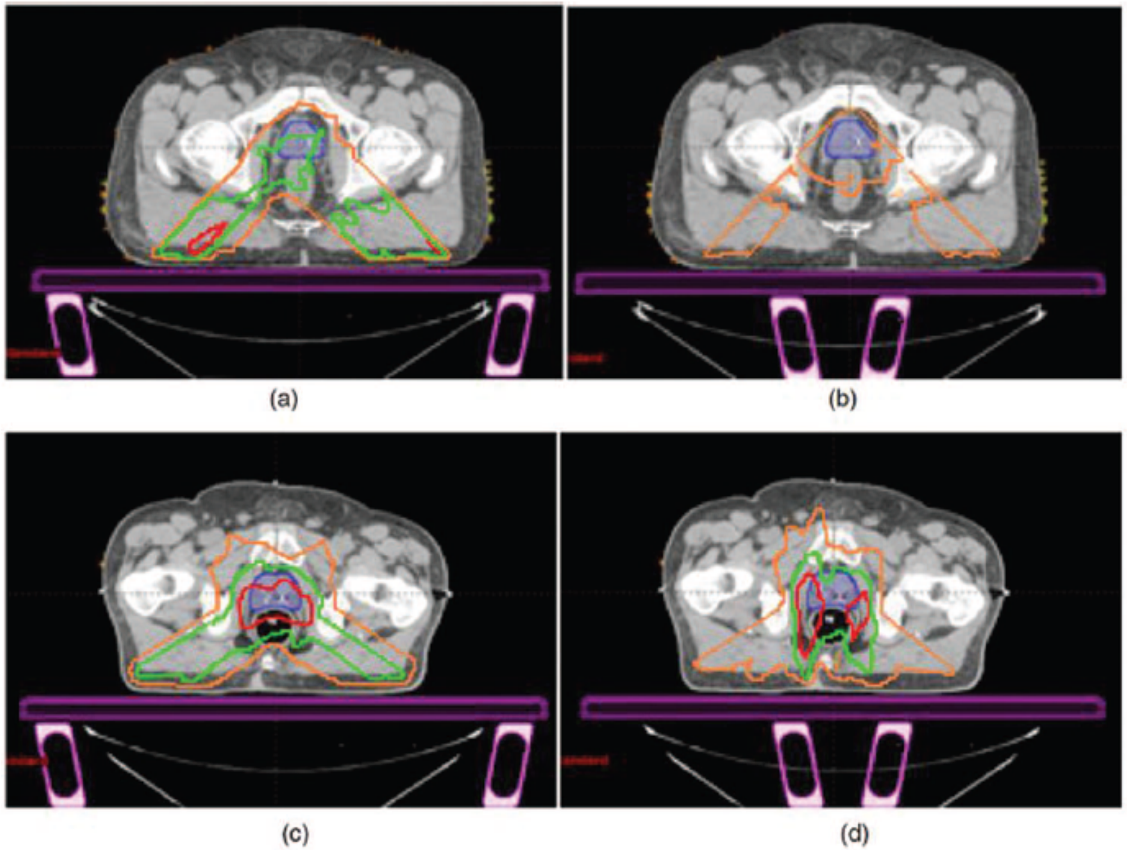
- Couch attenuation can be managed by:
  - using transmission factor in hand calculation
  - modeling the couch in the treatment planning system
  - do nothing (when attenuation is negligible)

couch models in the treatment planning system



Patient Support Systems: Couch Attenuation

- Some tables have adjustable support bars with high attenuation!
- Take care to make sure the beam doesn't enter through them



AAPM Task Group 176, "Dosimetric effects caused by couch tops and immobilization devices" (2014)

Immobilization Devices: Dosimetric Considerations

- Can be accounted for manually (using attenuation factor) or within the planning system
- Within TPS:
  - include in CT at time of simulation
- Measurements:
  - attenuation point measurements: ion chamber at depth in phantom
  - surface dose measurements:
    - extrapolation chamber
    - plane parallel chamber
    - OSL/TLD
    - Film

Immobilization Devices:
Measured Transmission Factors:

Material	6X	6X-FFF	10X	10X-FFF	15X
Cerrobend Tray	0.970	0.963	0.976	0.972	0.980
Slotted Tray	0.981	0.976	0.984	0.984	0.988
Solid Tray	0.968	0.961	0.975	0.971	0.977
Patient Slide Sheet	0.986	0.982	0.988	0.987	0.991
Wingboard	0.981	0.966	0.984	0.980	0.989
Breast Board	0.913	0.897	0.932	0.918	0.938
WFR AccuFix	0.972	0.970	0.978	0.974	0.982
Short Plastic Wingboard	0.984	0.972	0.987	0.981	0.992

Immobilization Devices

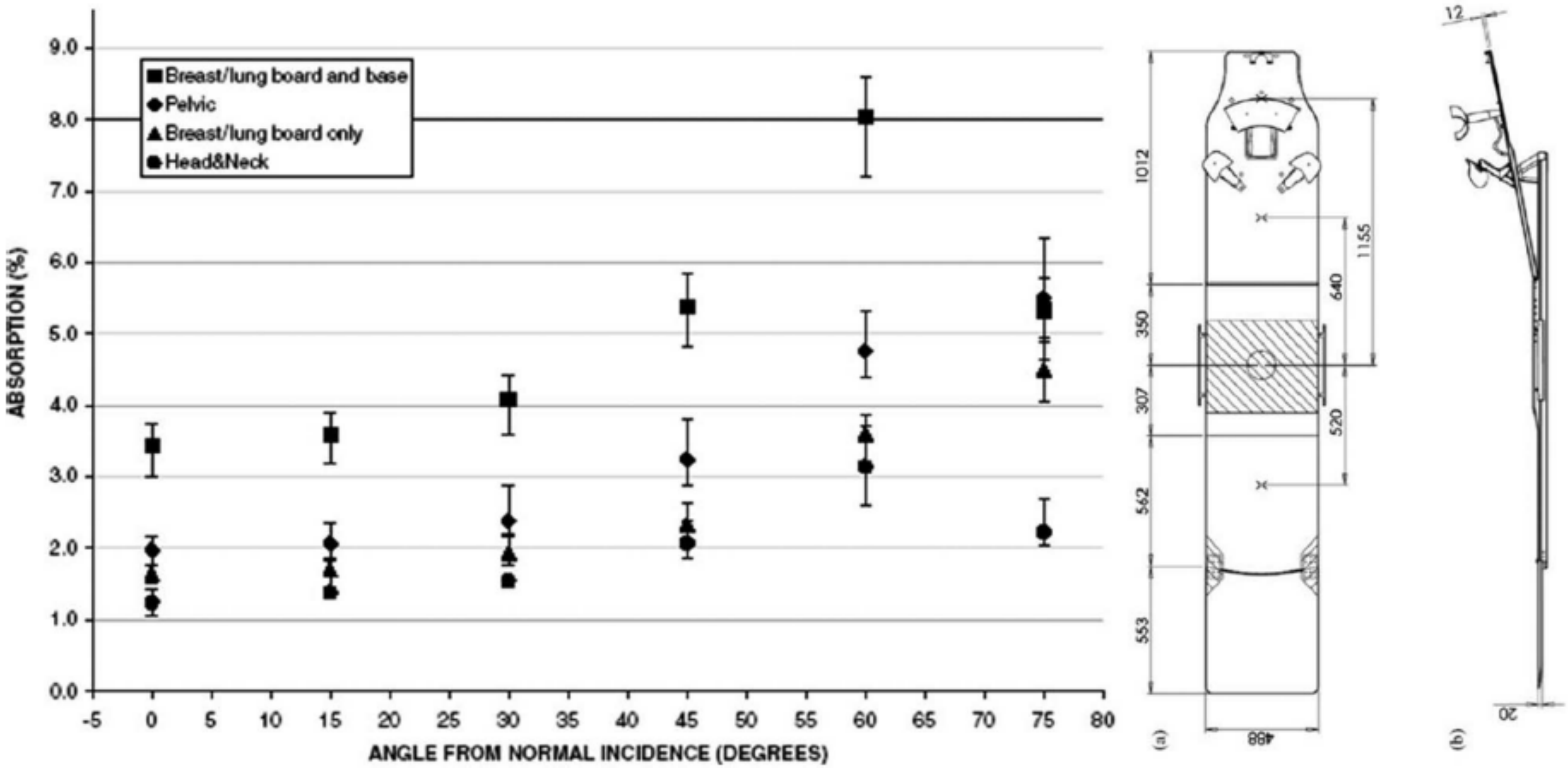


FIG. 6. Attenuation for the Contesse couchtop for 6 MV x-rays. From Berg *et al.*, "Absorption measurements on a new cone beam CT and IMRT compatible tabletop for use in external radiotherapy," Phys. Med. Biol. **54**, N319–N328 (2009).

AAPM Task Group 176, "Dosimetric effects caused by couch tops and immobilization devices" (2014)

Immobilization Devices

- Avoid entrance through devices when possible

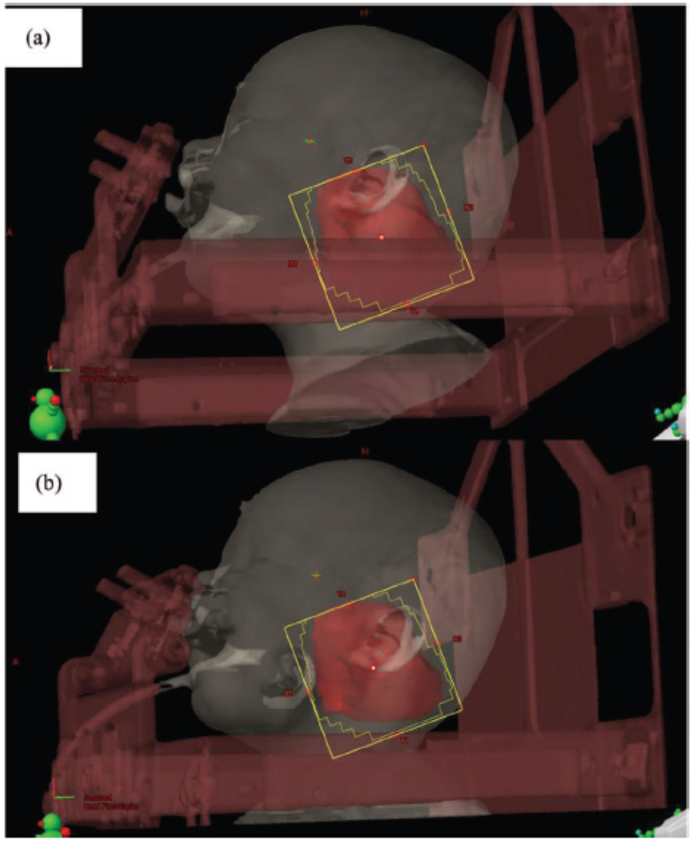


FIG. 16. (a) BEV of beam intersecting vertical post of immobilization device. (b) Gantry angle changed to avoid the post.

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THANK YOU

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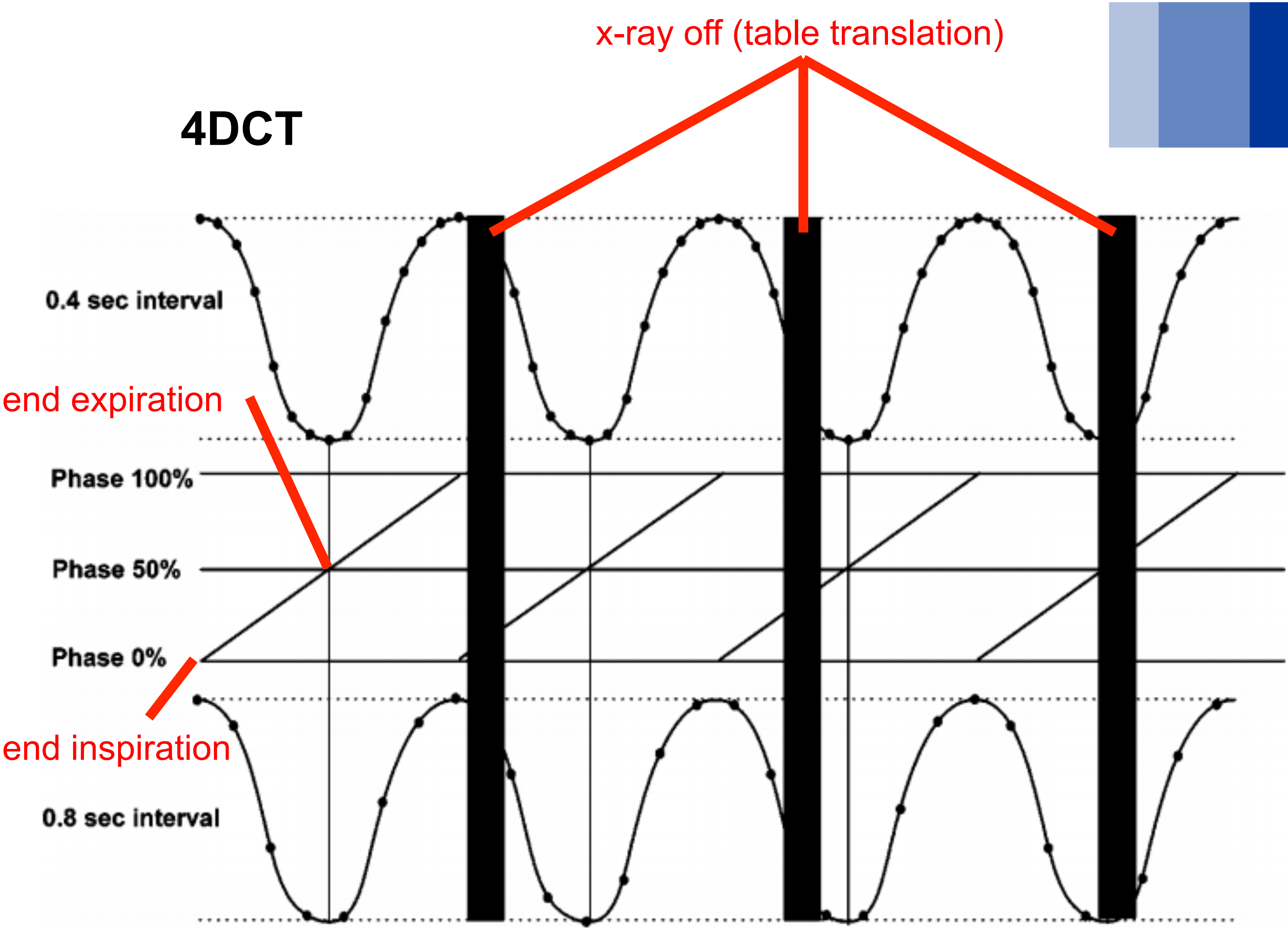
Additional Notes:

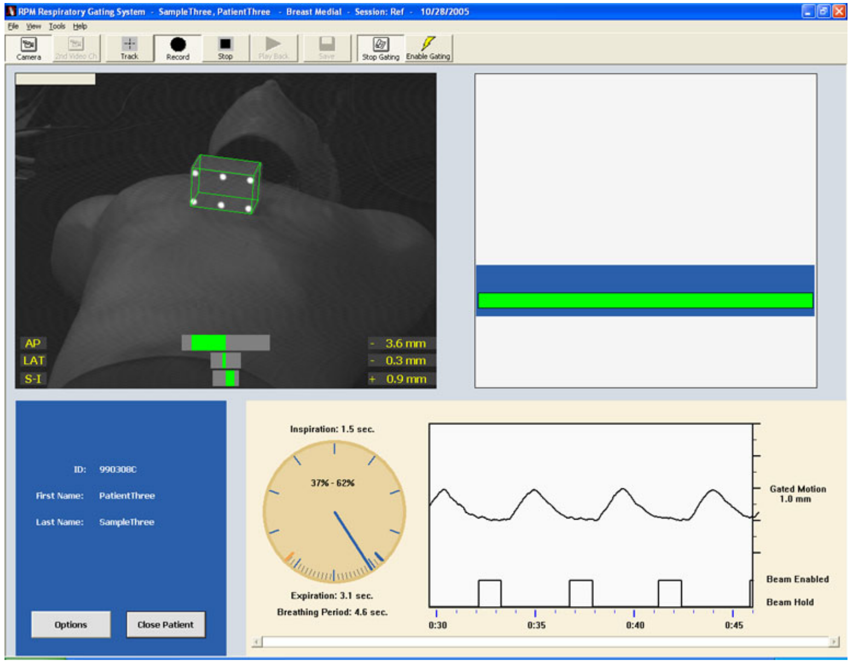
- CT Simulators often include tools for motion management
  - 4DCT
    - MIP
    - AIP
    - Min-IP
  - Breath hold CT

4DCT



Medical Physics, Vol. 31, No. 2, February 2004

4DCT Breathing Signal



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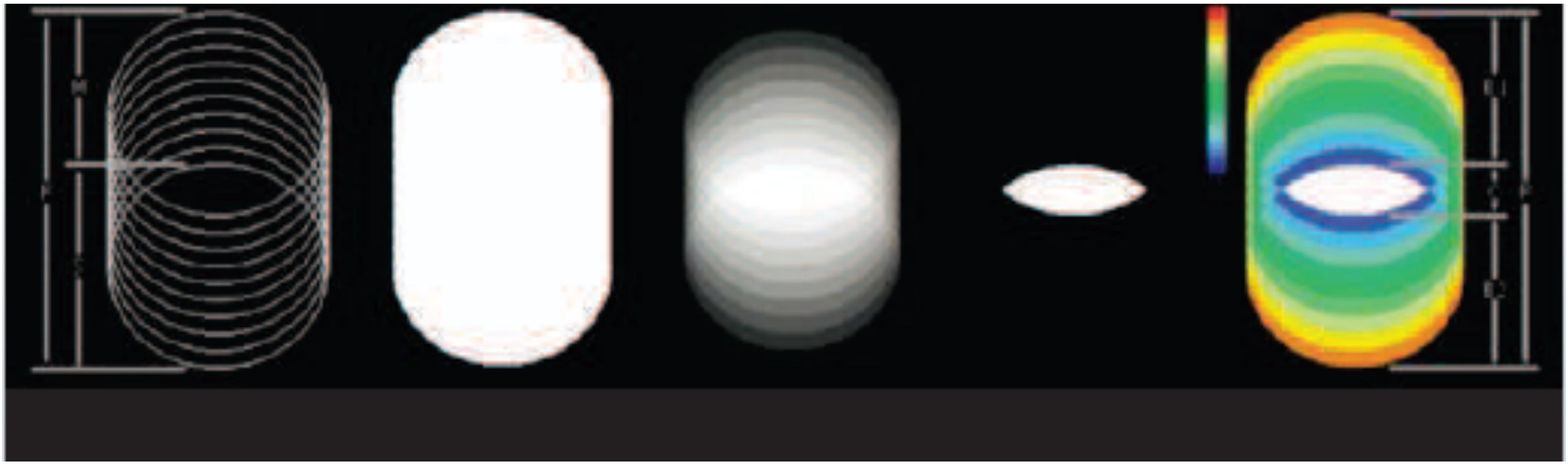
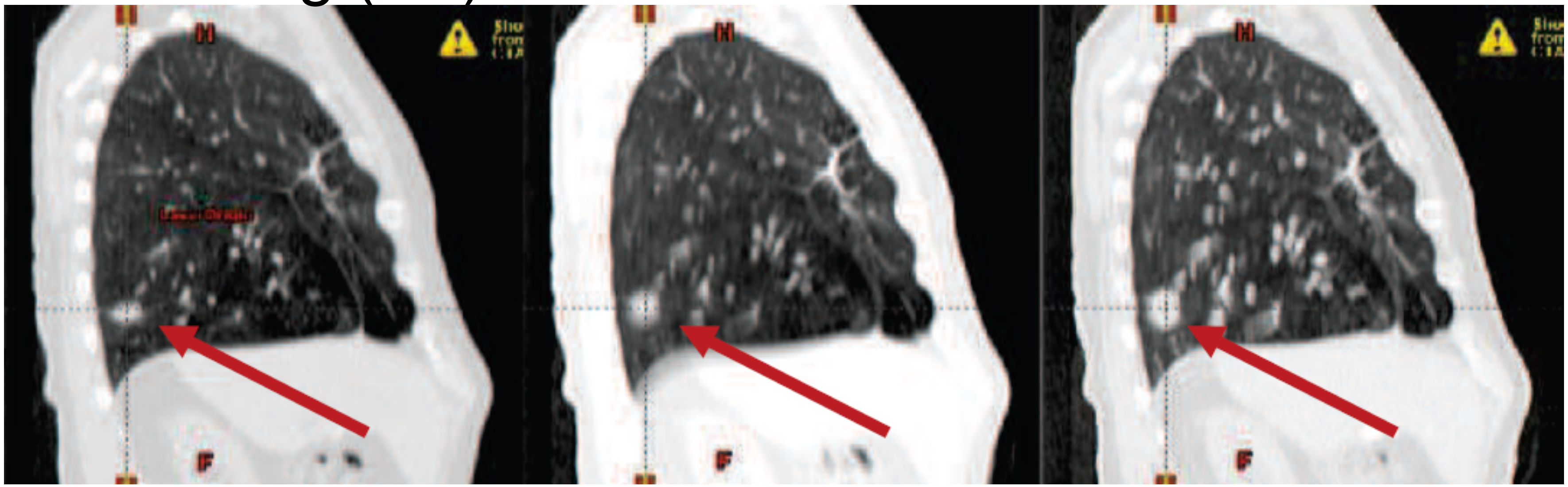
4DCT Reconstruction

Individual phases	Maximum Intensity Projection (MIP)	Average Intensity Projection (AIP)	Minimum Intensity Projection (MinIP)	Color AIP



4DCT

3D Free Breathing (FB) | 4DCT AIP | 4DCT MIP



Gating:

TABLE II. Monthly.

	Machine-typ	
Procedure	Non-IMRT	IMRT
Respiratory gating		
Beam output constancy		2%
Phase, amplitude beam control		Functional
In-room respiratory monitoring system		Functional
Gating interlock		Functional