CBCT technology for RT: Present and Future

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RADIATION ONCOLOGY

Road Map

- IGRT rationale
- Cone-Beam CT (CBCT) technical overview & characteristics:
  - Varian OBI, Elekta XVI, Siemens in-line kV/MV-CBCT
  - Image dose & quality
- QA
  - Daily, Monthly, Yearly QA recommendations
- CBCT clinical use & future work
  - Clinical workflow overview
  - IGART/DGRT overview: dose calc, Varian dynalog files, etc.
  - CBCT in lung tx: Fluroscopy, natural MIP, 4DCBCT
  - Cone-Beam Tomosynthesis
  - CBCT during VMAT

IGRT survey

9. Approximately what percentage of your current patients are treated using any of the in-room IGRT technologies specified in question 7?

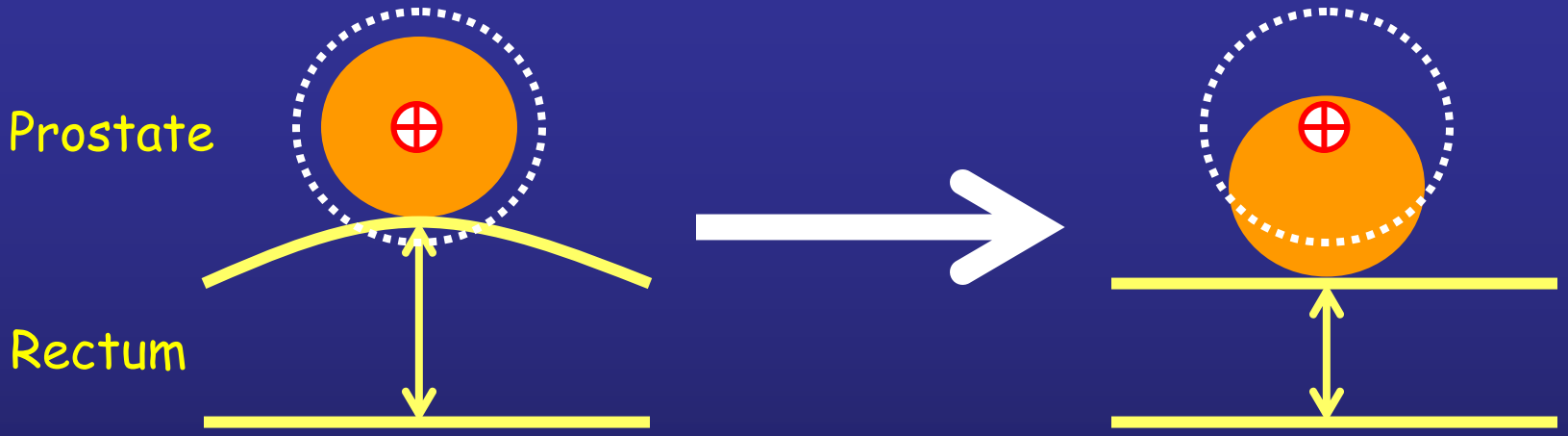
	Response Percent	Response Count
None	6.0%	22
<25%	27.2%	99
25-50%	**30.8%**	**112**
51-75%	17.3%	63
>75%	18.7%	68
answered question		364
skipped question		7

11. What are your future plans for in-room IGRT technologies?

	Response Percent	Response Count
Do not plan to adopt	1.6%	6
Maintain current use	38.3%	140
Start using / Increase use	**59.8%**	**219**
Stop using / Decrease use	0.3%	1
answered question		366
skipped question		5

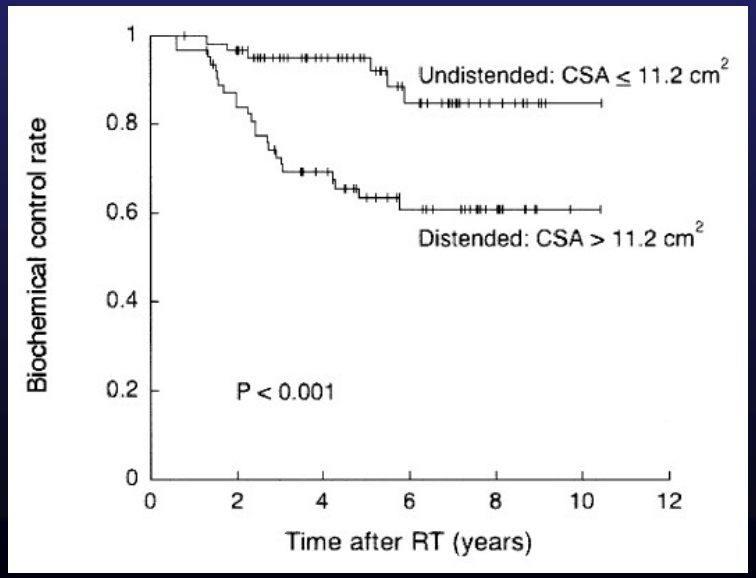
Courtesy: Dr Danny Simpson

Why IGRT?



Distended rectum at CT sim

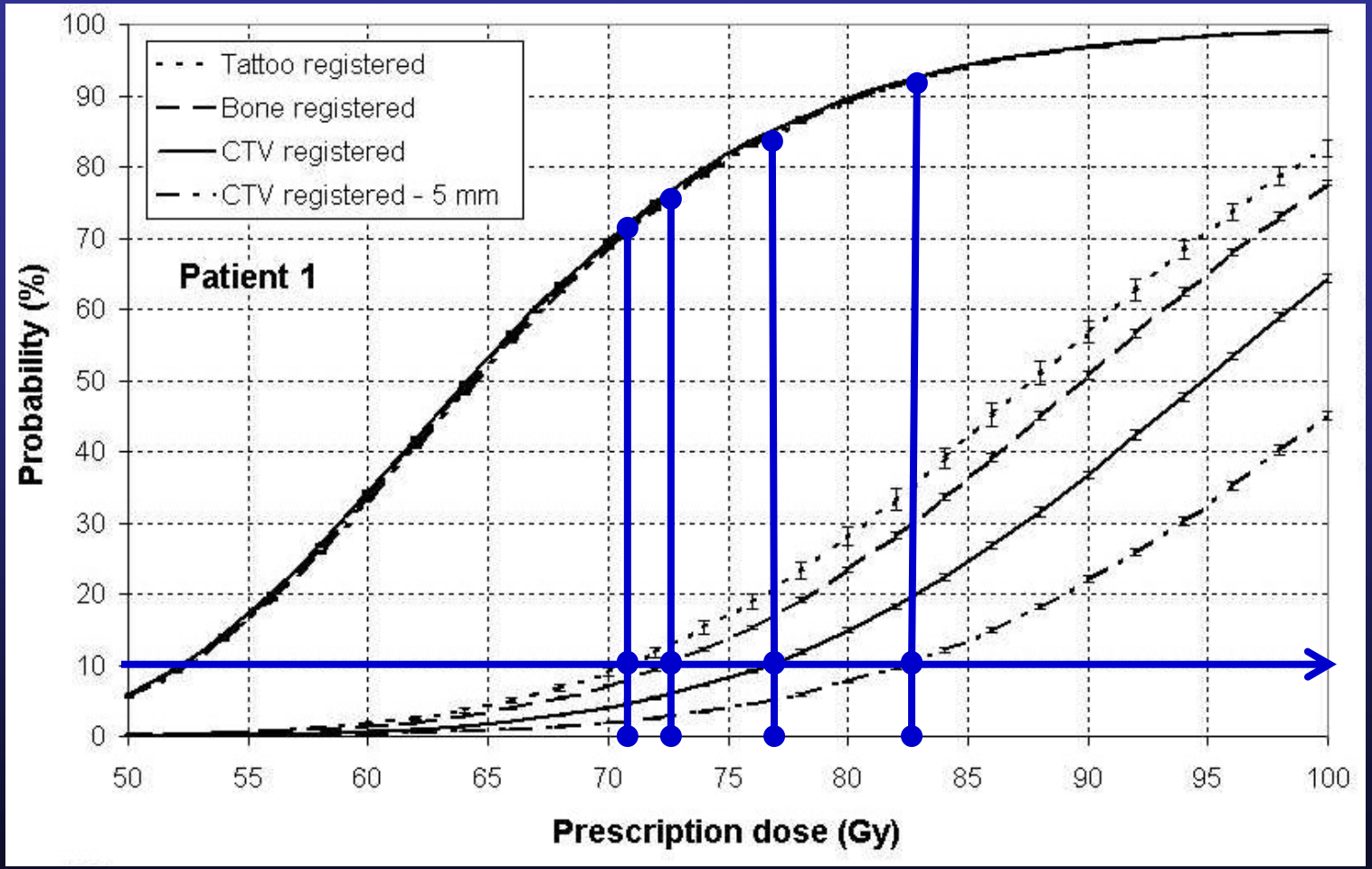
Normal rectum at Tx day



De Crevoisier et al. *Red J* 2005

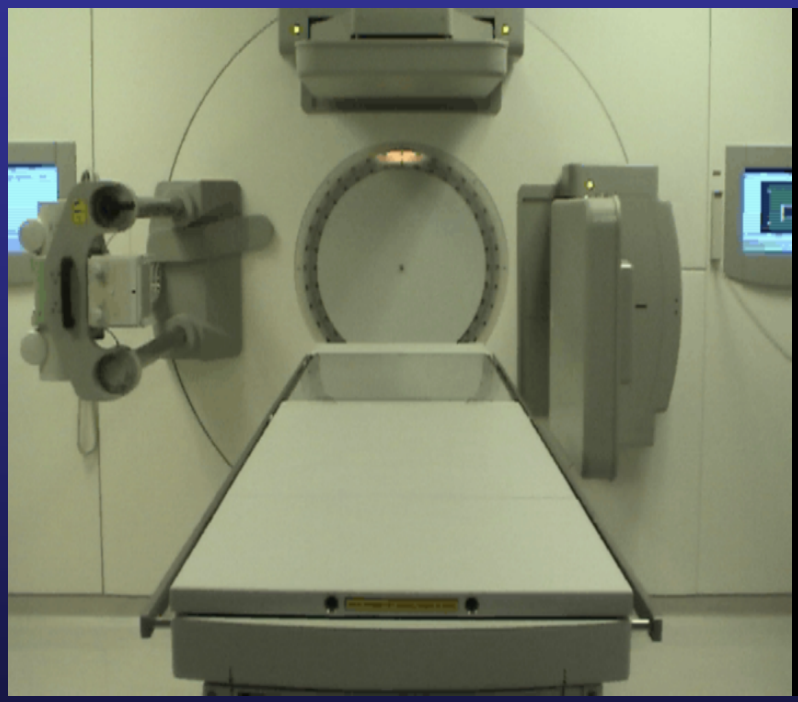
1) Sig. decrease in biochemical control.
2) Sig. decrease in late rectal bleeding.

Why IGRT?



Song *et al.*, Med Phys 2005;32:2193-2203

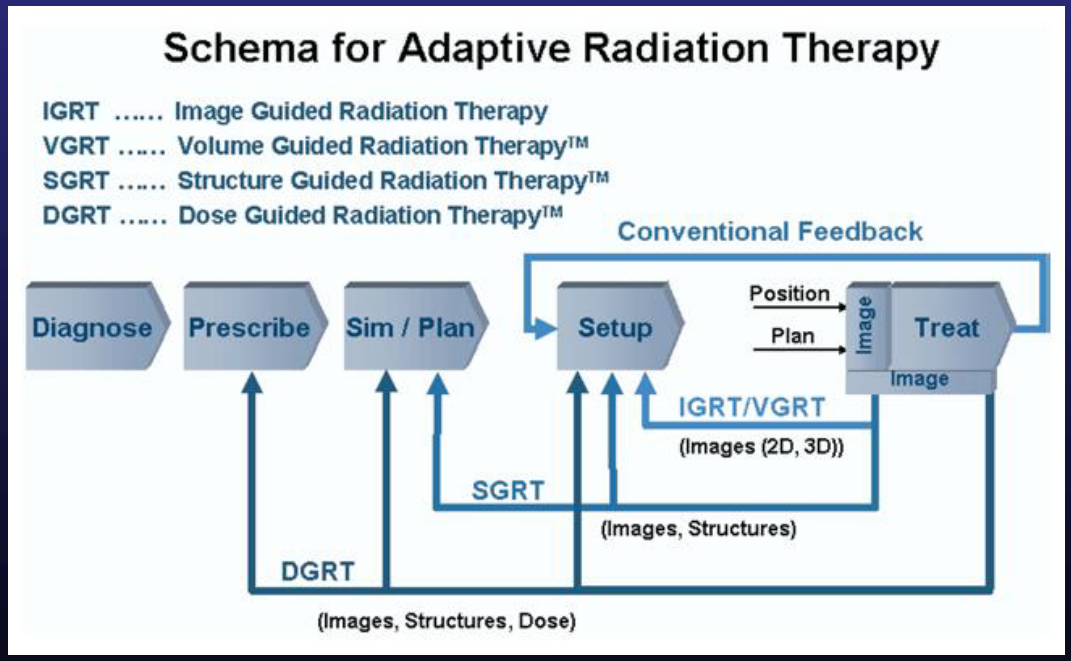
In-Room CBCT



Courtesy: Dr David Jaffray

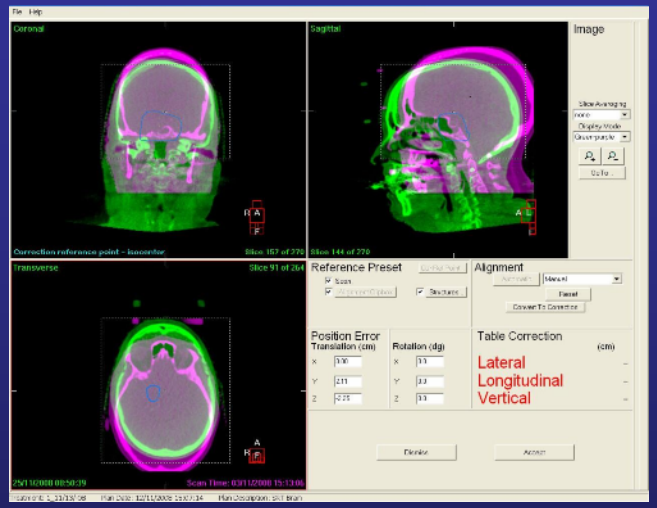
CBCT overview

- Commercial systems:
  - Elekta XVI®
  - Varian OBI ®
  - Siemens in-line kV/MV-CBCT



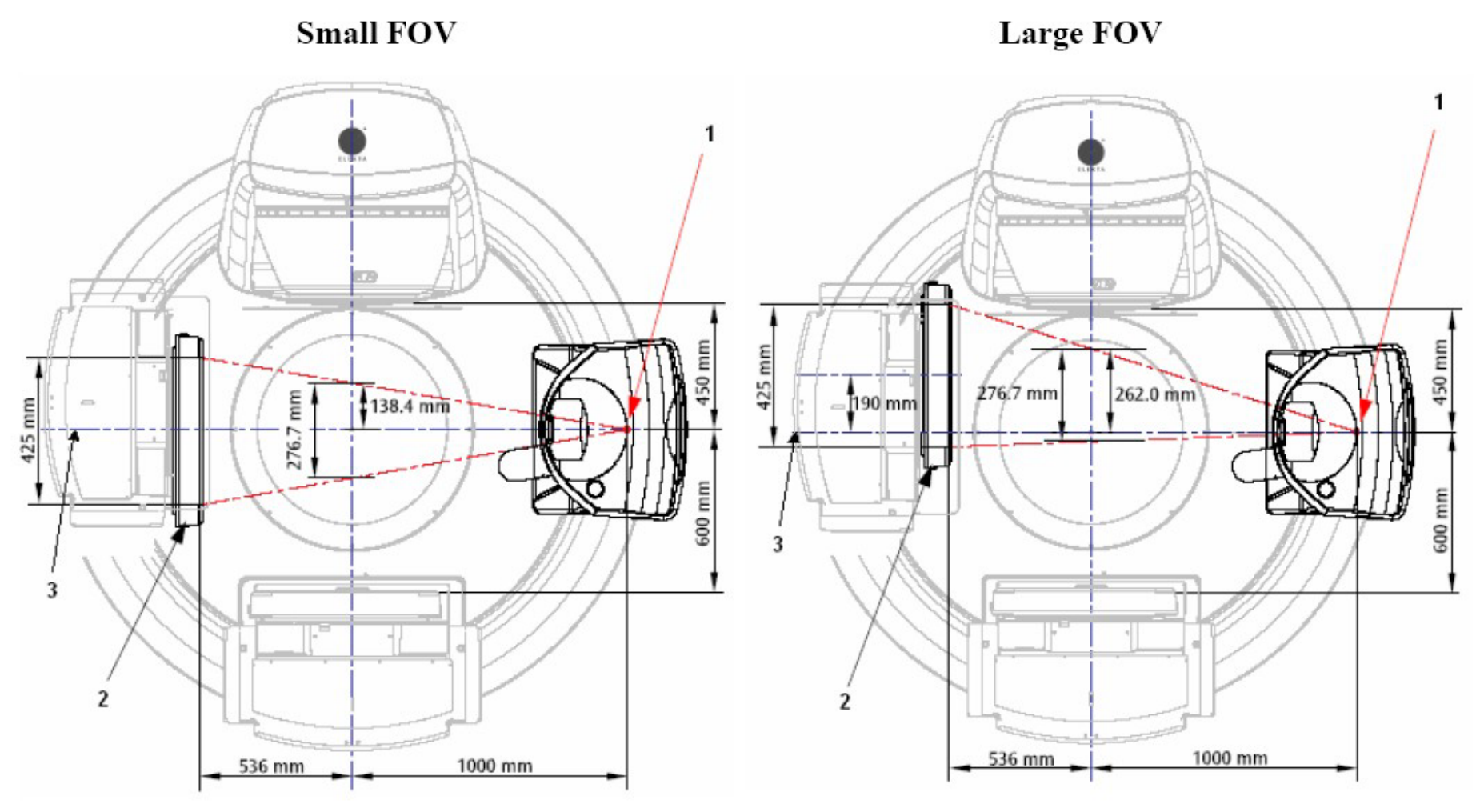
Amies *et al.*, Med Dosim 2006;31:12-19

Elekta XVI®

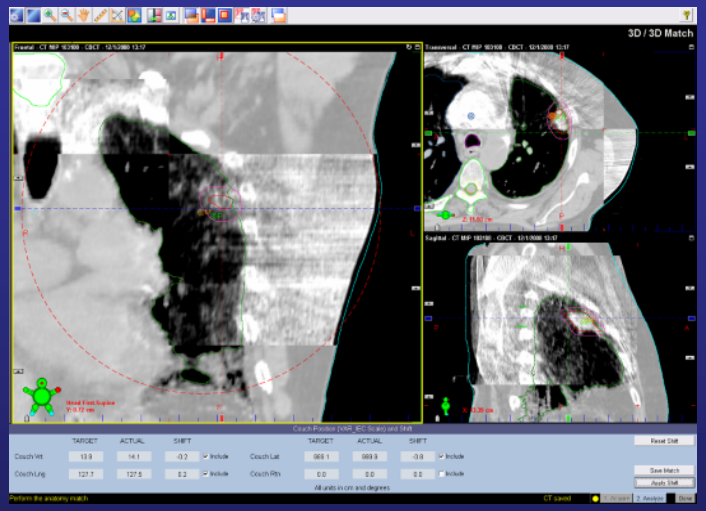


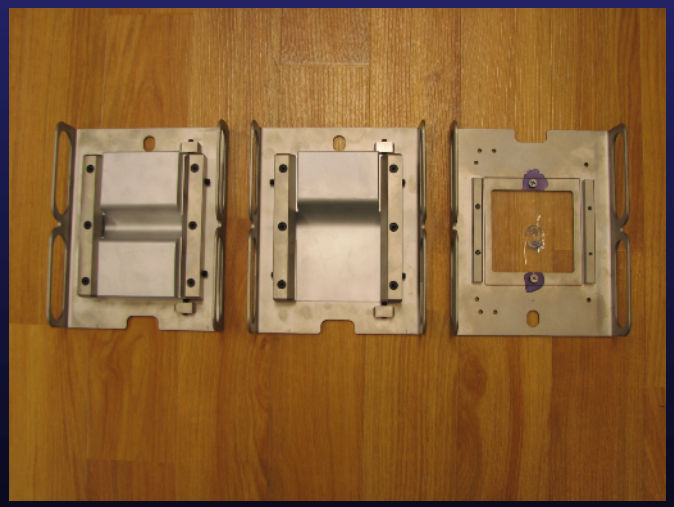
- Capability:
  - Planar, Fluoroscopic, 3DCBCT
  - 100, 120 kVp used
- Scanning modes:
  - Small, Medium, Large
- Bow-Tie Filter:
  - Optional

Elekta XVI®


Small FOV
Large FOV
1
2
3
425 mm
276.7 mm
138.4 mm
450 mm
600 mm
536 mm
1000 mm
190 mm
262.0 mm

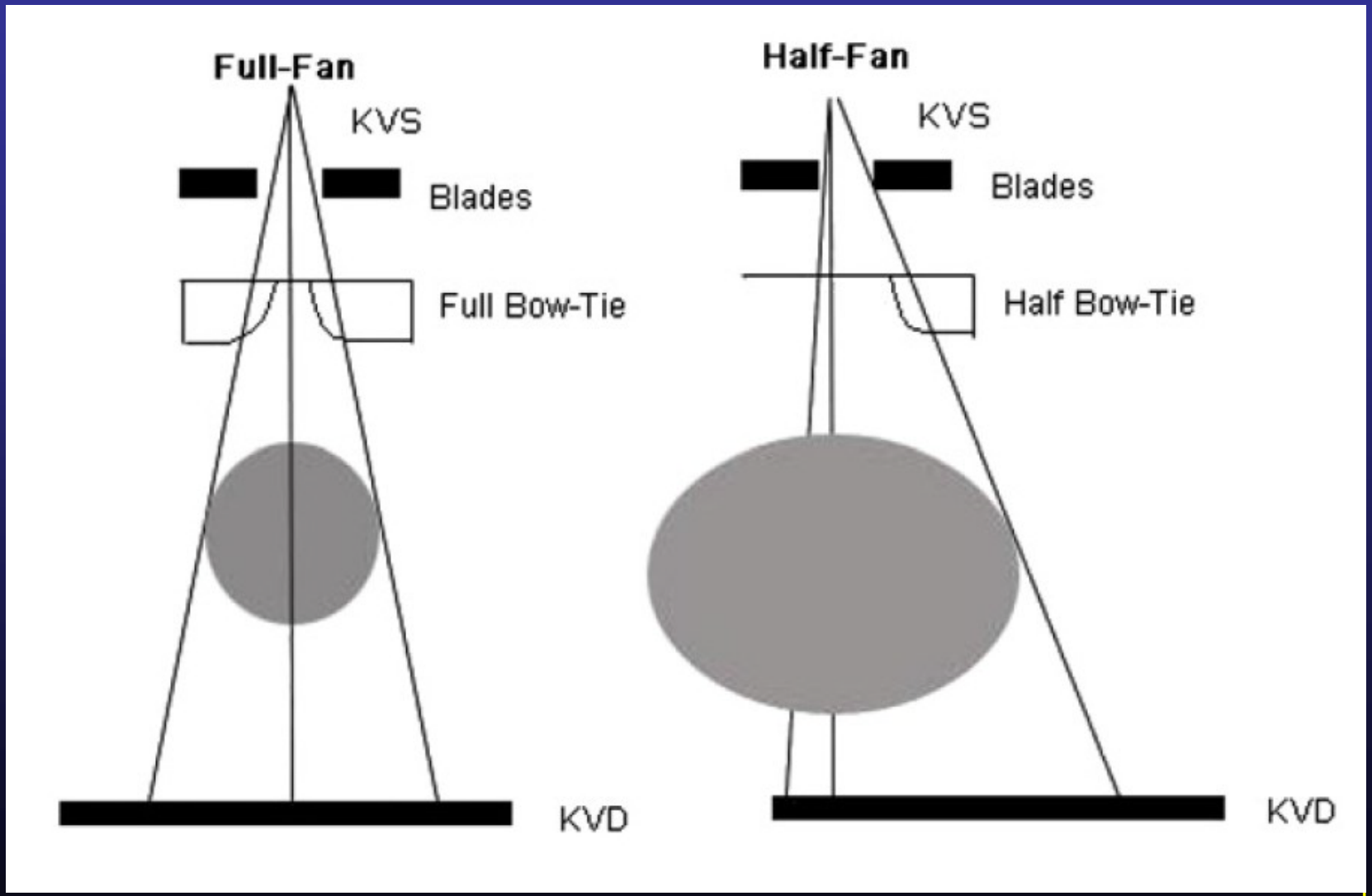
Varian OBI®



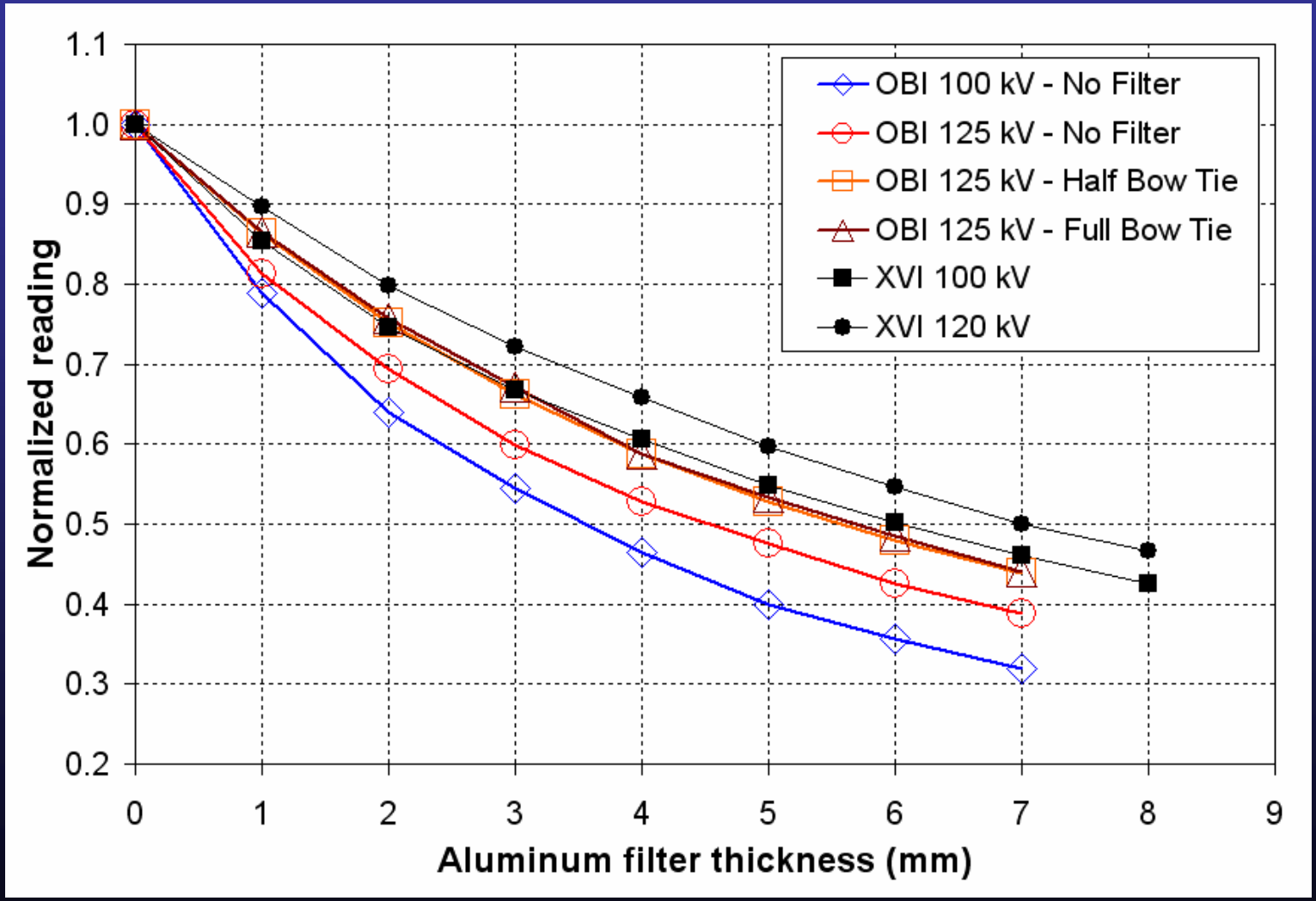


- Capability:
  - Planar, Fluoroscopic, 3DCBCT
  - 100, 120 kVp used
- Scanning modes:
  - Half-Fan, Full-Fan
- Bow-Tie Filter:
  - Optional

Varian OBI®


Full-Fan
KVS
Blades
Full Bow-Tie
KVD
Half-Fan
KVS
Blades
Half Bow-Tie
KVD

HVL – "narrow" beam geometry



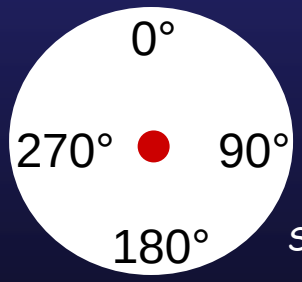
HVL – "narrow" beam geometry

Machine	XVI		OBI			
X-ray Energy	100 kVp	120 kVp	100 kVp	125 kVp		
Filter	No Filter		No Filter	No Filter	Half Bow Tie	Full Bow Tie
HVL (mm-Al)	6.0	7.0	3.5	4.6	5.7	5.7

- OBI 100 kVp not used clinically
- OBI has higher kVp
- XVI has "harder" beams

CBCT dose study

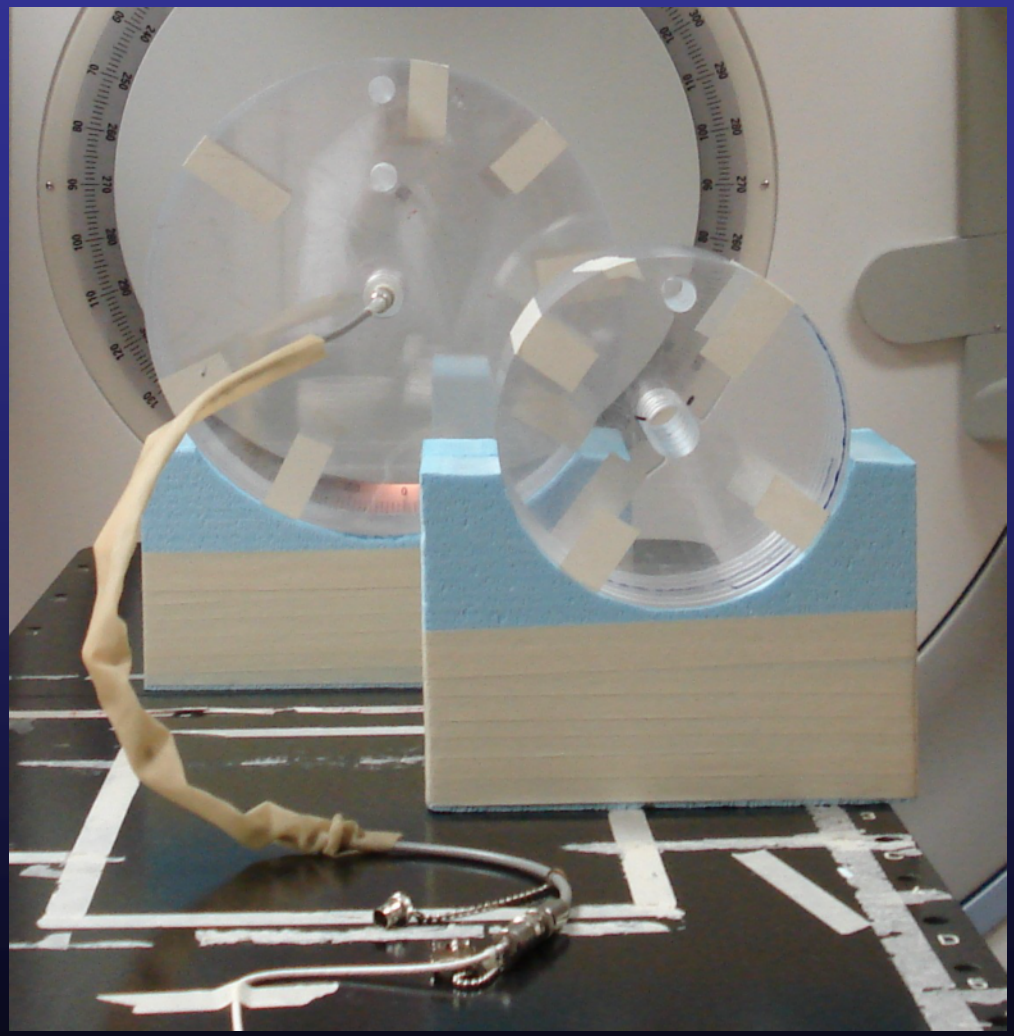
- kV CBCT systems (vendor-installed):
  - Elekta Synergy™ with XVI®
  - Varian Trilogy™ with OBI®
- Two acrylic cylindrical phantoms
- 0.6cc Farmer-type ion chamber used with appropriate air-kerma calibration factor, N_k (TG61 protocol)



Song *et al.*, Med Phys 2008;35:480-486

- Beam qualities in HVLs of mm-Al

CBCT dose



Acrylic phantoms:

1) Head phantom
   18cm-diameter
2) Body phantom
   30cm-diameter

Hole at center and 2cm from the surface
0.6cc Farmer-type chamber

Song *et al.*, Med Phys 2008;35:480-486

Elekta XVI®

Protocol	*head & neck*	*prostate*	*pelvis*	*chest*
Phantom Size (cm)	18	30	30	30
kV Collimator	S20	M10	M20	L20
kVp	100	120	120	120
mA	10	40	25	25
ms/frame	10	40	40	40
# frames	361	643	643	643
Total mAs	36.1	1028.8	643	643
Acquisition Angle	350° to 190° *cw*	273° to 269° *cw*	273° to 269° *cw*	273° to 269° *cw*
Dose (cGy)				
$D_{central}$	0.10 ± 0.01	2.2 ± 0.04	1.6 ± 0.04	1.1 ± 0.03
Edge: 0°	0.13 ± 0.01	4.3 ± 0.05	2.8 ± 0.03	2.2 ± 0.01
Edge: 90°	0.22 ± 0.01	4.1 ± 0.01	2.7 ± 0.01	2.1 ± 0.03
Edge: 180°	0.13 ± 0.01	3.7 ± 0.03	2.5 ± 0.01	2.0 ± 0.03
Edge: 270°	0.22 ± 0.01	4.6 ± 0.01	3.1 ± 0.01	2.4 ± 0.01
$D_{peripheral}$	0.14 ± 0.06	4.2 ± 0.39	2.8 ± 0.24	2.2 ± 0.17
$CBCTDI_w$	**0.1**	**3.5**	**2.4**	**1.8**

Varian OBI®

Protocol	150cm-FSD with Bow Tie		150cm-FSD Low Dose		150cm-FSD No Bow Tie	
Phantom Size (cm)	18	30	18	30	18	30
Filter	Full Bow Tie	Half Bow Tie	Full Bow Tie	Half Bow Tie	None	None
Scan Mode	*full-fan*	*half-fan*	*full-fan*	*half-fan*	*full-fan*	*half-fan*
kVp	125		125		125	
mA	80	80	40	40	40	40
ms/frame	25	25	10	10	10	10
# frames	630		630		630	
Total mAs	1260	1260	252	252	252	252
Acquisition Angle	85.5° to 92.5° *cw* or 94.5° to 87.5° *ccw*		85.5° to 92.5° *cw* or 94.5° to 87.5° *ccw*		85.5° to 92.5° *cw* or 94.5° to 87.5° *ccw*	
Dose (cGy)						
$D_{central}$	8.5 ± 0.12	4.1 ± 0.09	1.8 ± 0.02	0.9 ± 0.01	2.5 ± 0.05	1.1 ± 0.03
Edge: 0°	8.7 ± 0.33	6.3 ± 0.04	1.8 ± 0.07	1.3 ± 0.02	3.5 ± 0.06	2.5 ± 0.02
Edge: 90°	8.1 ± 0.17	7.5 ± 0.35	1.6 ± 0.03	1.6 ± 0.06	3.1 ± 0.02	2.7 ± 0.10
Edge: 180°	7.5 ± 0.01	4.8 ± 0.27	1.5 ± 0.01	1.0 ± 0.05	2.8 ± 0.01	2.0 ± 0.04
Edge: 270°	8.1 ± 0.04	5.7 ± 0.02	1.7 ± 0.01	1.2 ± 0.01	3.0 ± 0.01	2.1 ± 0.02
$D_{peripheral}$	8.1 ± 0.52	6.1 ± 1.13	1.7 ± 0.13	1.3 ± 0.25	3.1 ± 0.29	2.3 ± 0.34
$CBCTDI_w$	**8.3**	**5.4**	**1.7**	**1.1**	**2.9**	**1.9**

Varian OBI®

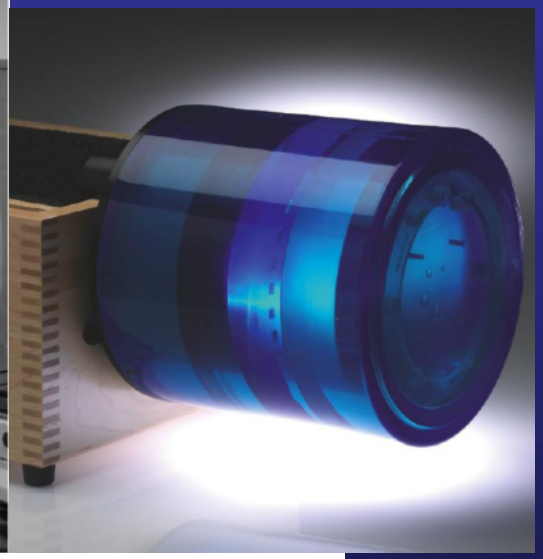
Monte Carlo dose calculation study:

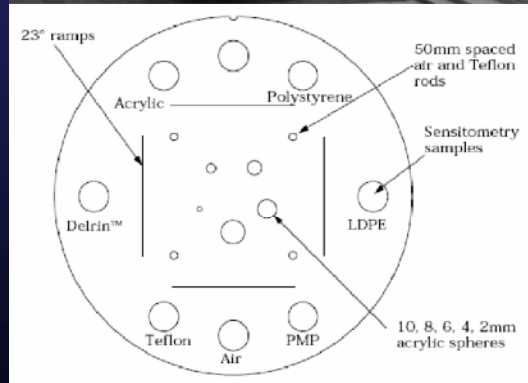
Table 1. Range of radiation dose to soft tissue and bone within imaged volume (20-cm length) for head-and-neck, chest, and abdominal treatment sites of adults and small pediatric patients resulting from a single kilovoltage cone beam computed tomography scan in clinical default half-fan mode settings, unless specified otherwise

Dose to organs (cGy)	Head and neck (adult)	Head and neck (pediatric)	Abdominal (large adult)	Abdominal (pediatric)	Chest (adult)
Eye	7–8 5–6 (full-fan)	7–8 5–6 (full-fan)			
Brain	3.5–5.5 2.4–5.4 (full-fan)	4.8–6.7 3.8–5.8 (full-fan)			
Cord	4.5–5.5 4–4.5 (full-fan)	6–7 5.5–6.5 (full-fan)			3–4.5
Thyroid	6–9 6–8 (full-fan)	7–10 7–9 (full-fan)			
Prostate			3	7–8	
Ovary			3–4	7–8	
Intestine			3–4	6–8	
Lung					3–6
Heart					3–6
Soft tissue (including skin)	3–9 3–7 (full-fan)	4–10 3–9 (full-fan)	1–5	3–9	2–9
Bone	11–28 8–21 (full-fan)	14–29 13–24 (full-fan)	6–11	9–29	9–24

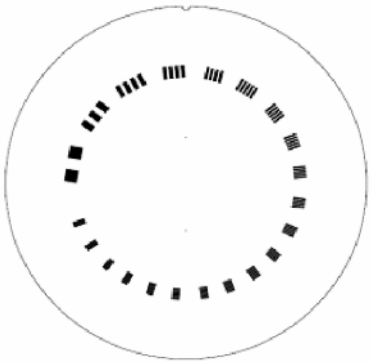
Ding *et al.*, Red J 2009;73:610-617

CBCT image quality

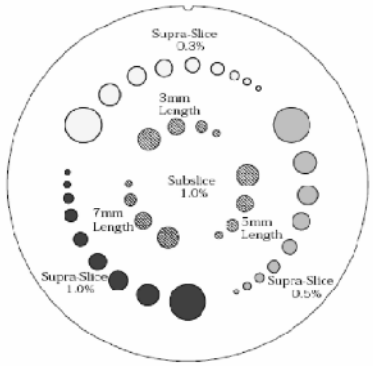




(a)



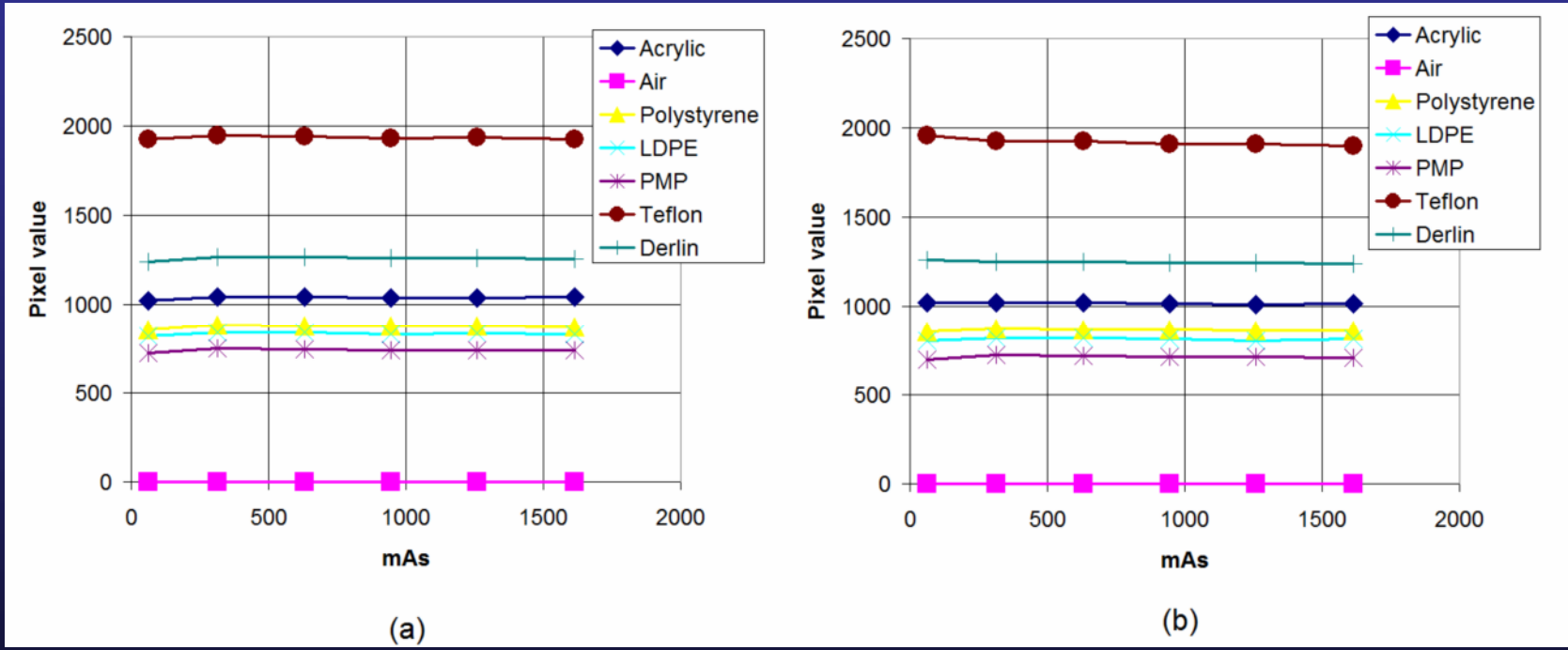
(b)



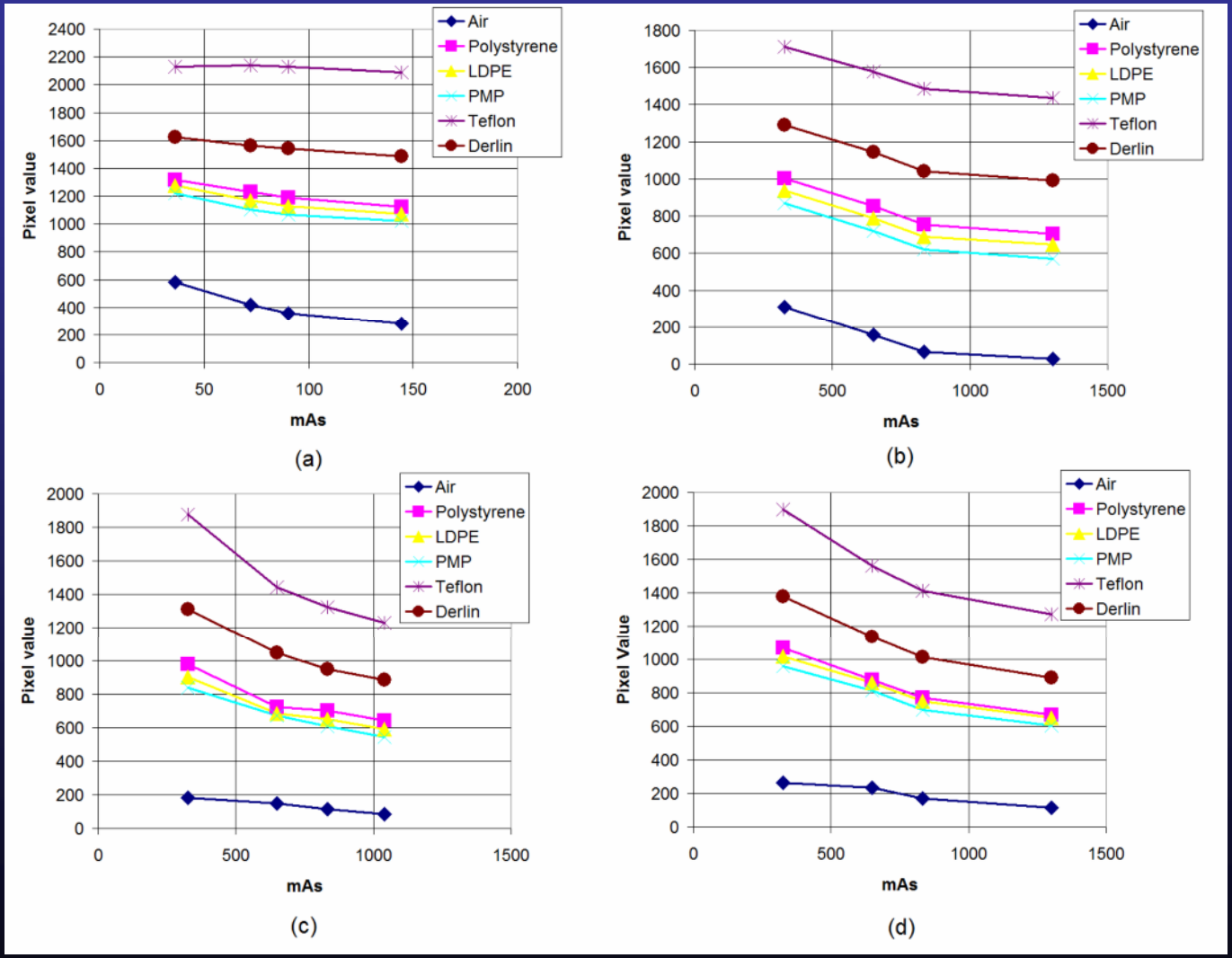
(c)

Kamath *et al.*, Med Phys 2009 (in revision)

Varian OBI®

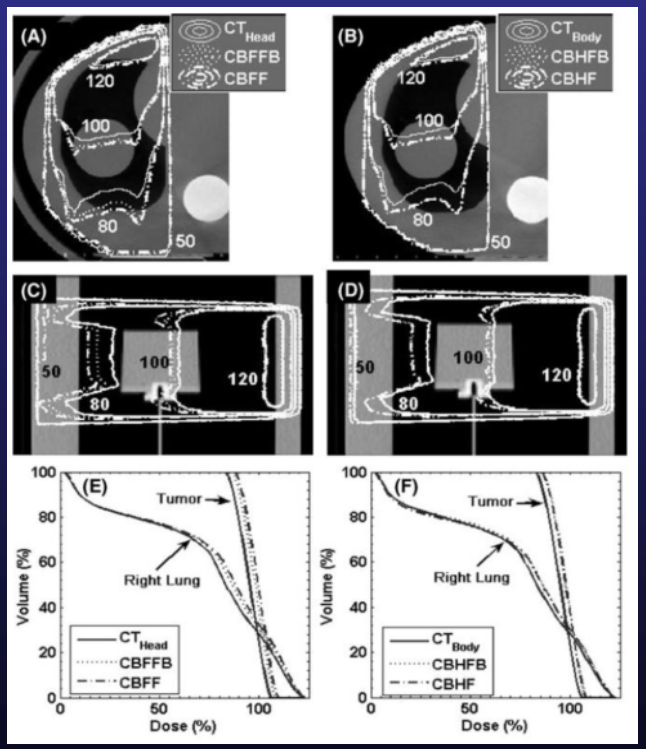

2500
2000
1500
1000
500
0
Pixel value
0
500
1000
1500
2000
mAs
Acrylic
Air
Polystyrene
LDPE
PMP
Teflon
Derlin
(a)
(b)

Elekta XVI®

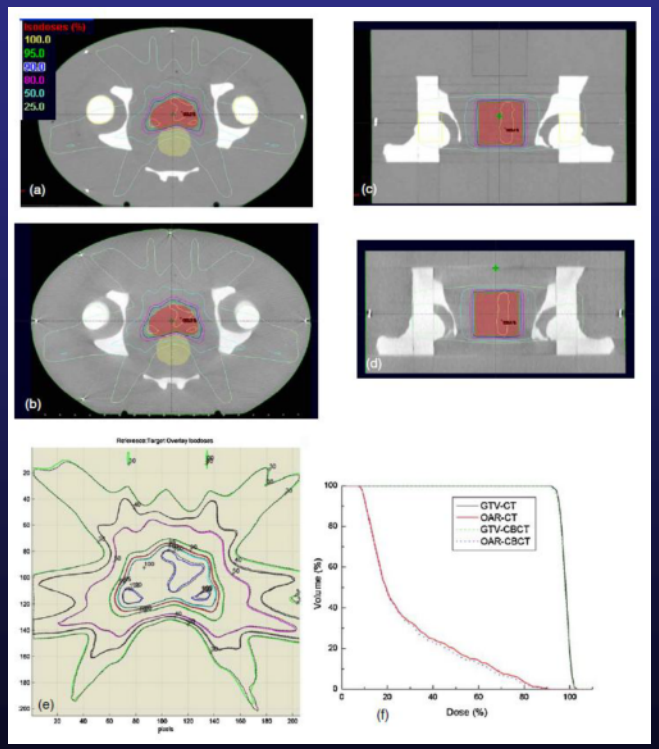

Air
Polystyrene
LDPE
PMP
Teflon
Derlin
Pixel value
mAs
(a)
(b)
(c)
(d)

Dose calc on CBCT images

- No feasibility study has been published-to-date using the XVI system
- For OBI system:
  - Agreement within 2%/2mm for most situations
  - In lung, due to organ motion, errors can be > 5% (~ few hundred HU offset)

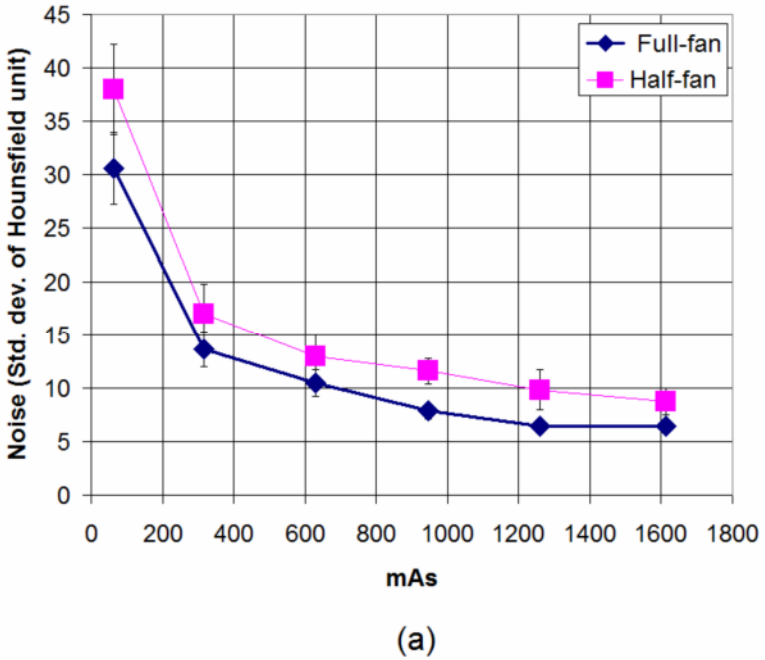


Yoo *et al.*, Red J 2006;66:1553-1561



Yang *et al.*, PMB 2007;52:685-705

Image noise


Noise (Std. dev. of Hounsfield unit)
mAs
Full-fan
Half-fan
(a)

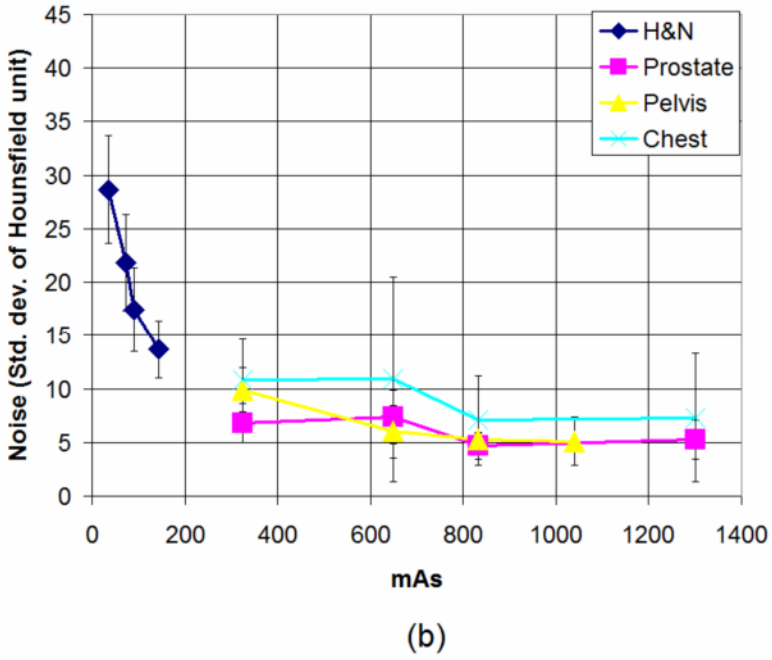
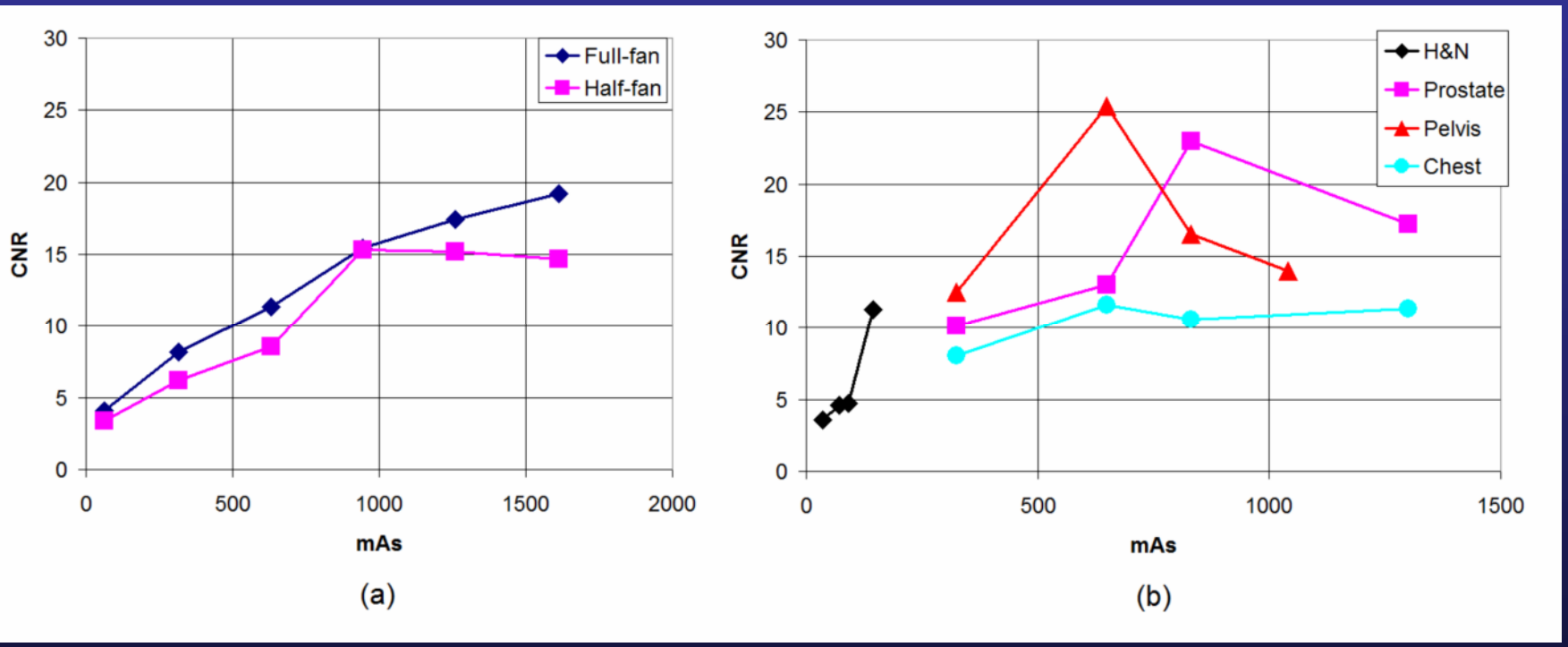
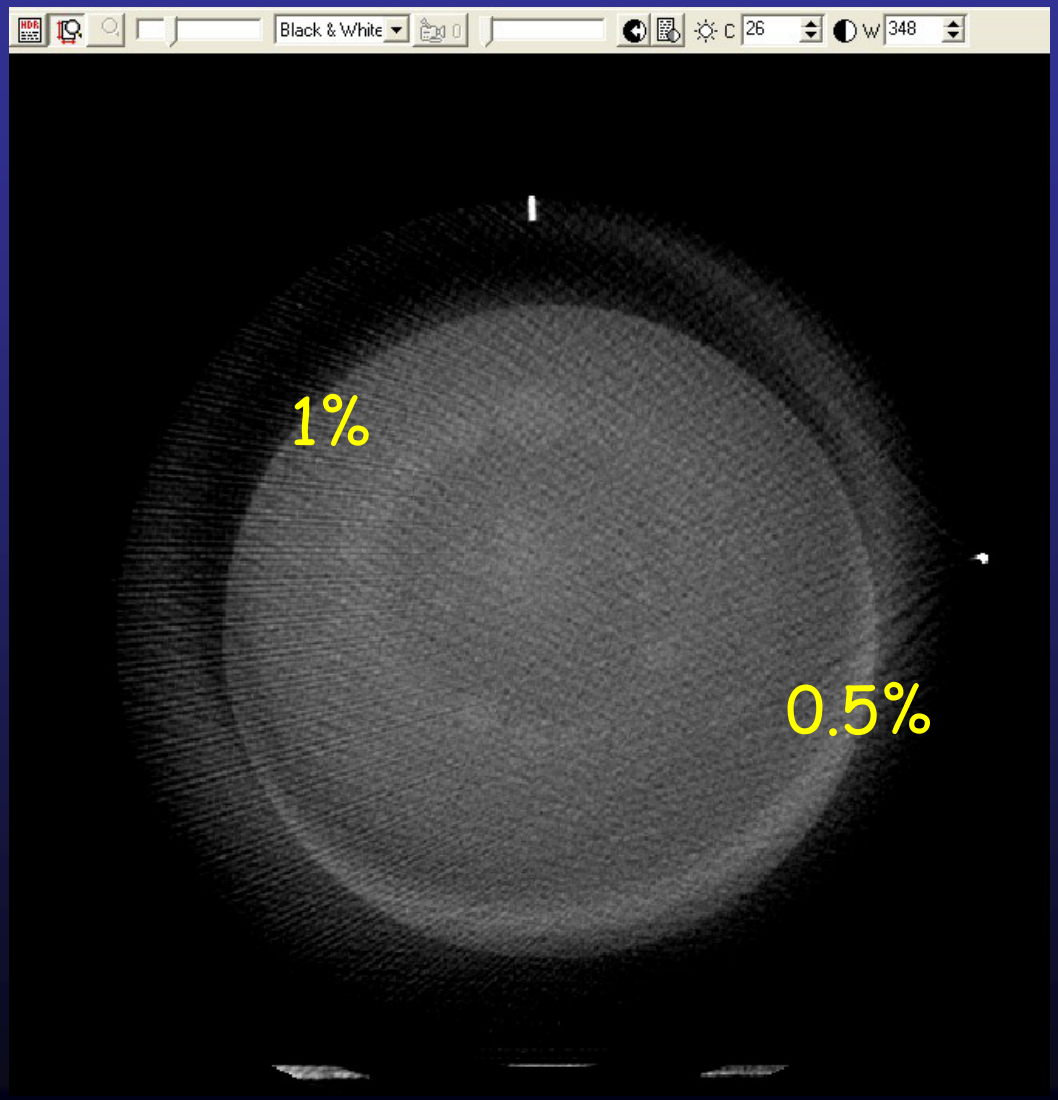

Noise (Std. dev. of Hounsfield unit)
mAs
H&N
Prostate
Pelvis
Chest
(b)

Image CNR


30
25
20
15
10
5
0
CNR
0
500
1000
1500
2000
mAs
Full-fan
Half-fan
(a)
30
25
20
15
10
5
0
CNR
0
500
1000
1500
mAs
H&N
Prostate
Pelvis
Chest
(b)

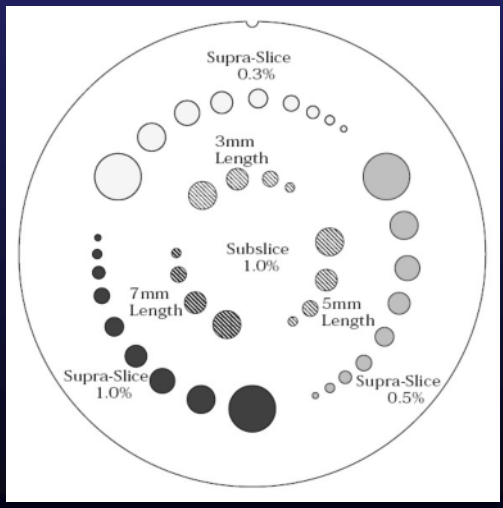
OBI: Full-Fan Mode



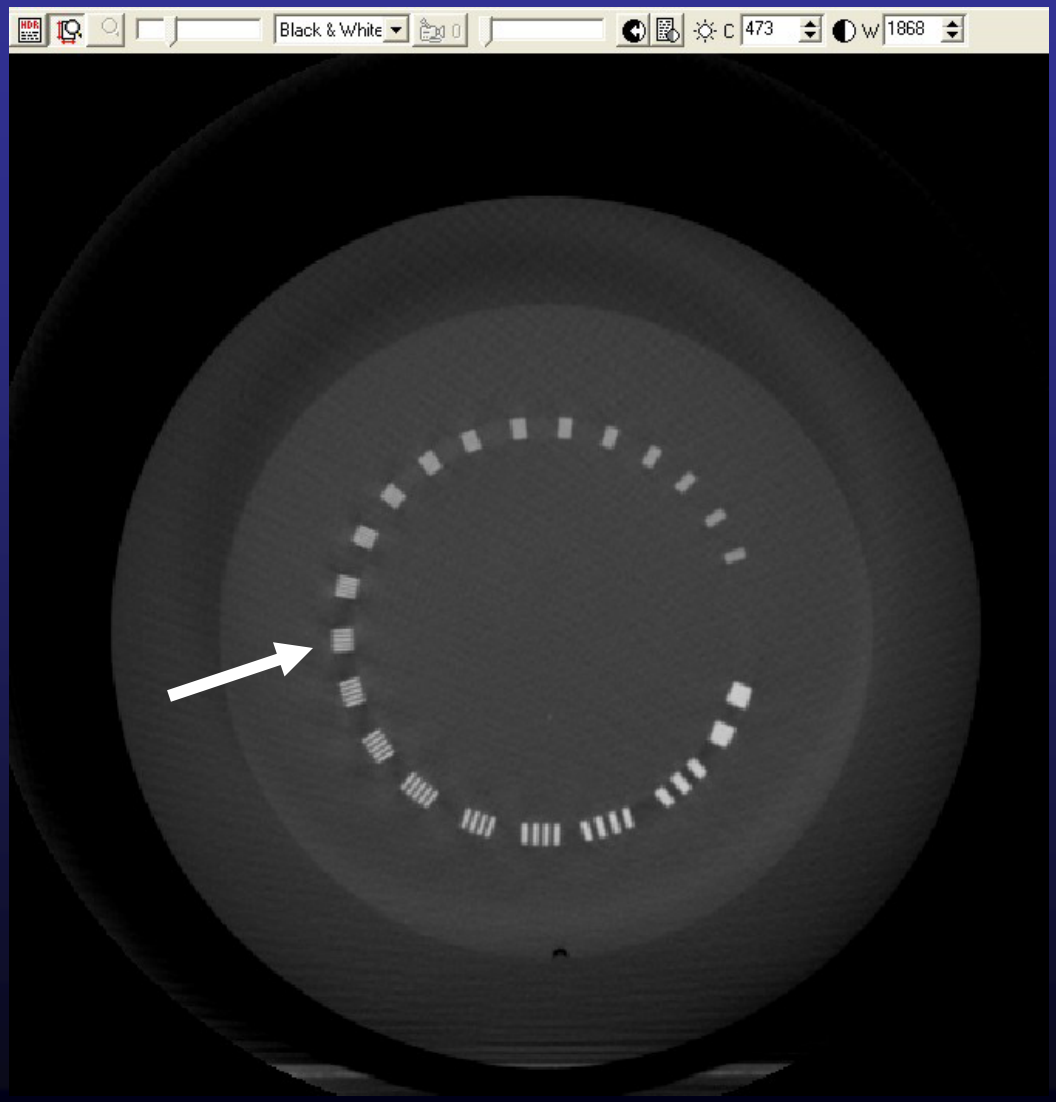
24-cm FOV

0.3% contrast is not visible

$CBCTDI_w$ = 8.3cGy

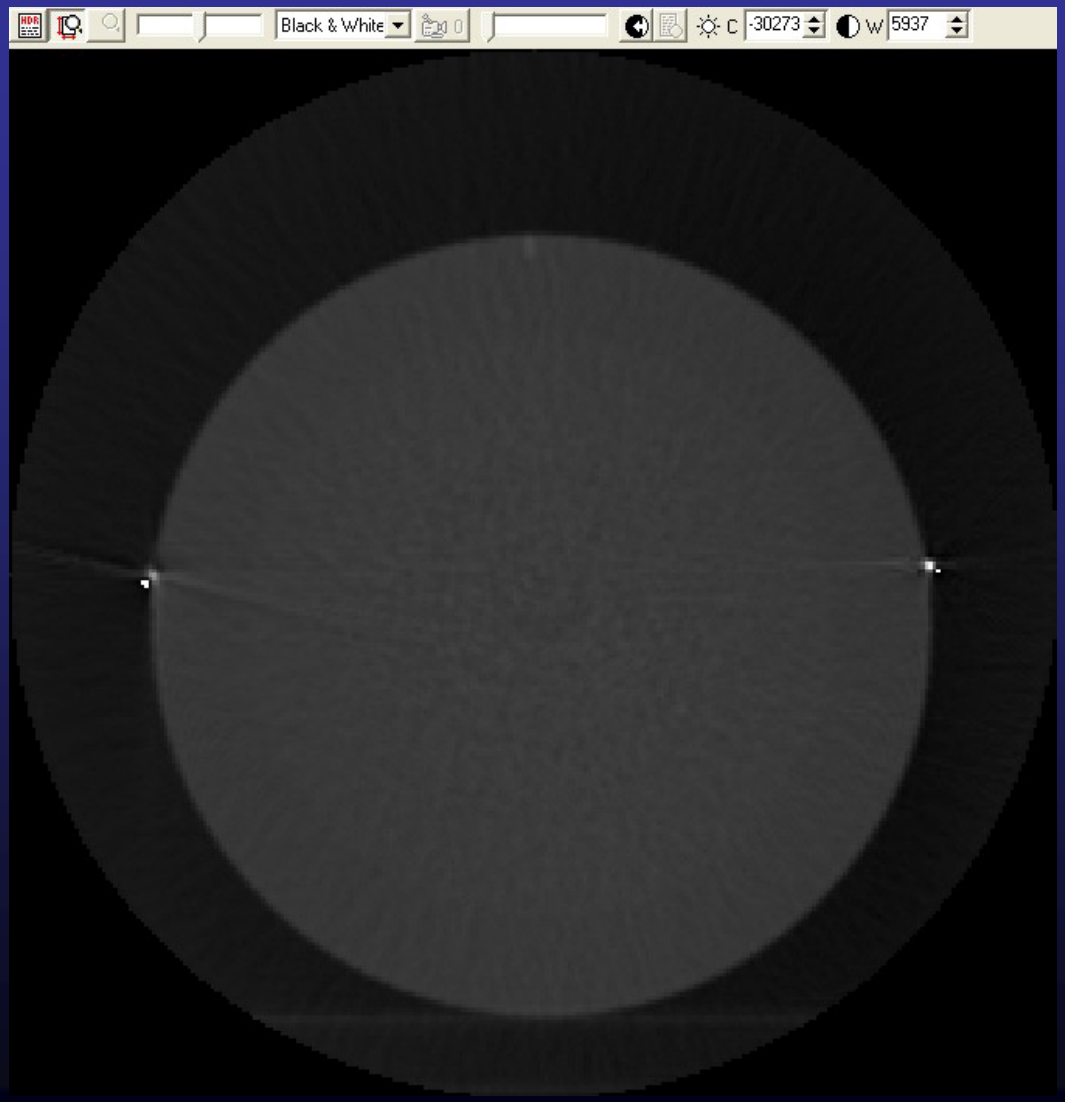


OBI: Full-Fan Mode



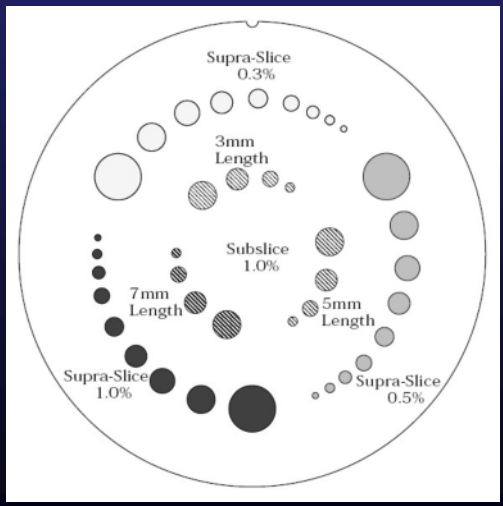
Resolution limit:
9 lp/cm

XVI: H&N protocol

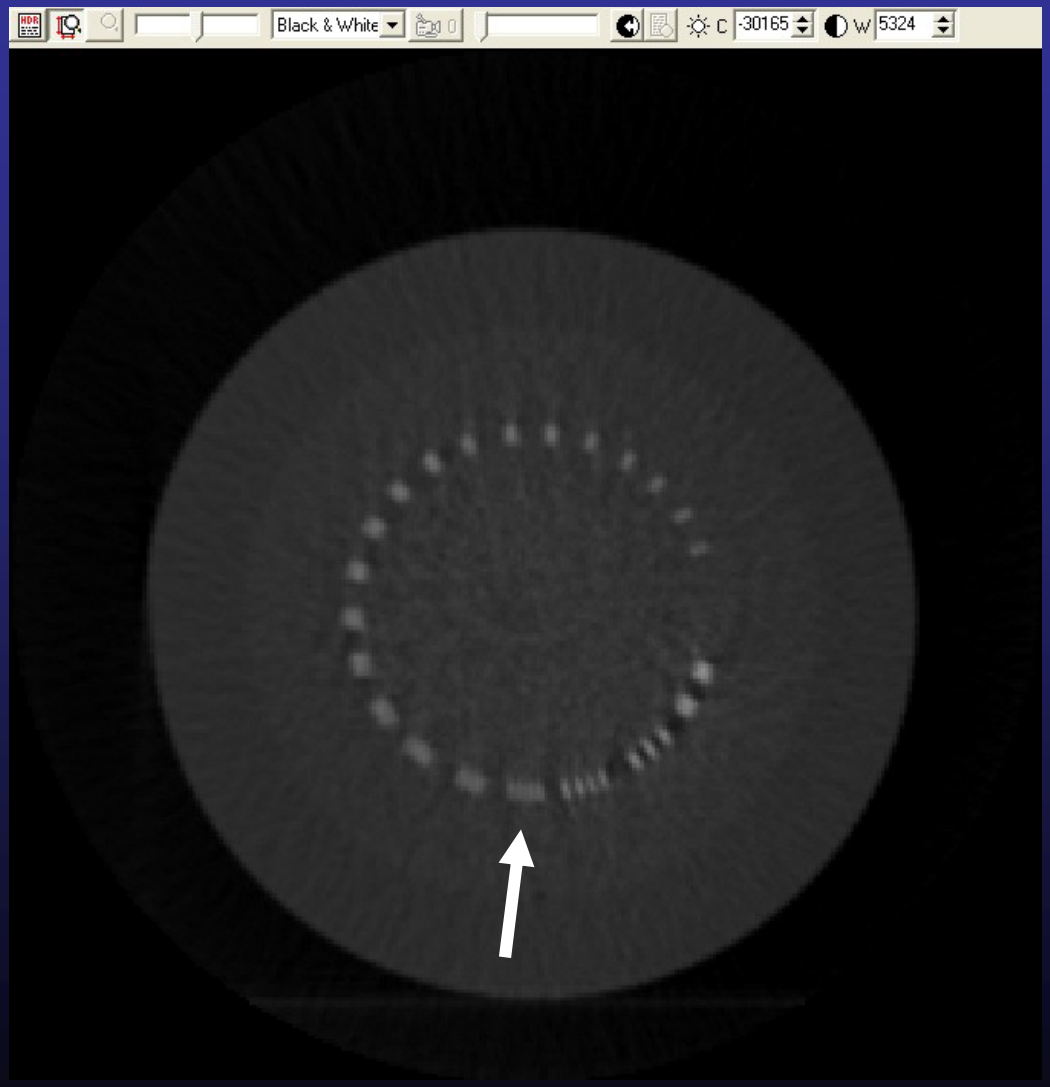


None are visible

$CBCTDI_w$ = 0.1cGy



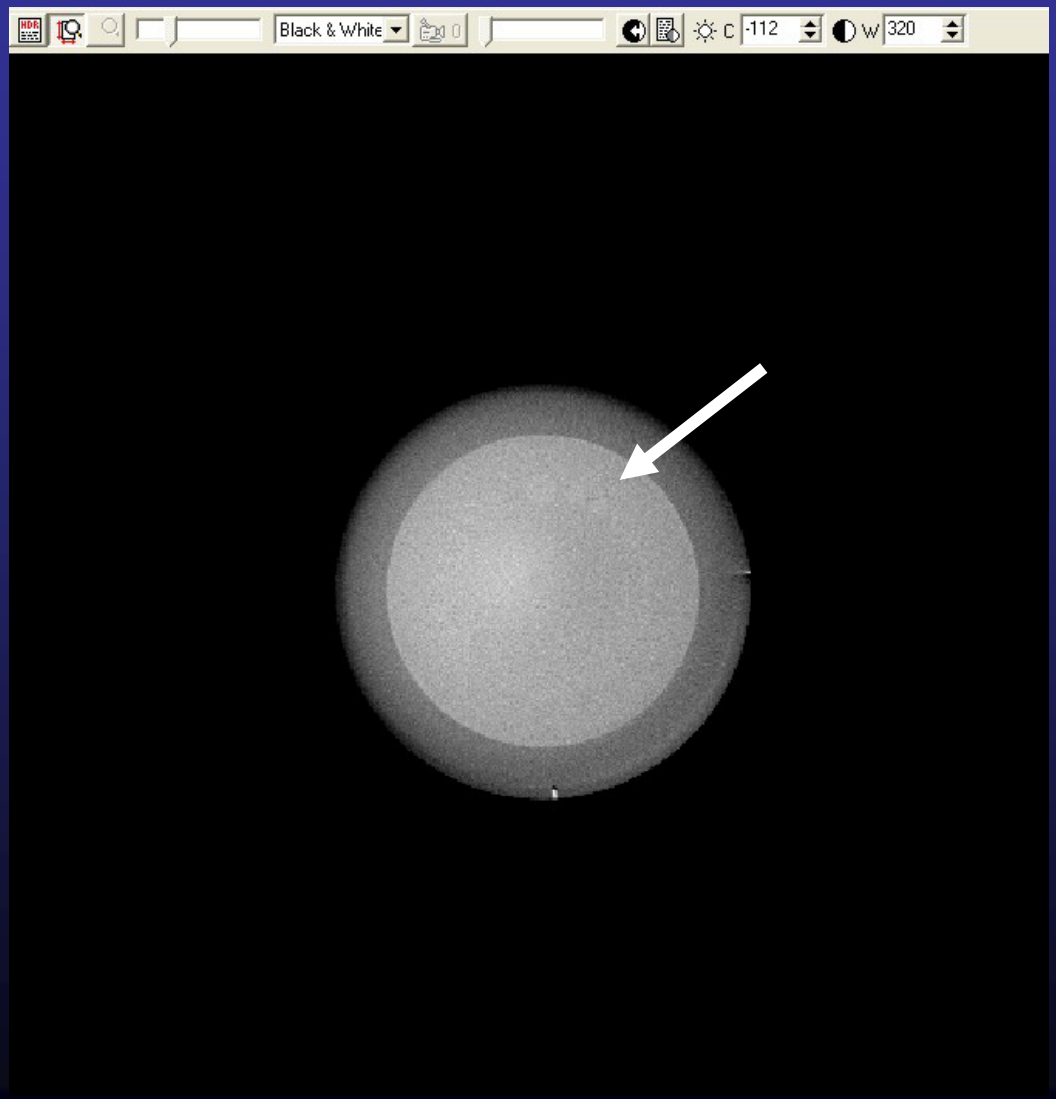
XVI: H&N protocol



Resolution limit:
4 lp/cm

$CBCTDI_w$ = 0.1cGy

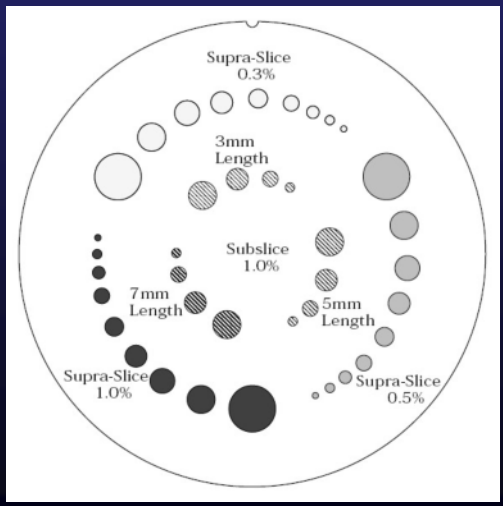
OBI: Half-Fan Mode



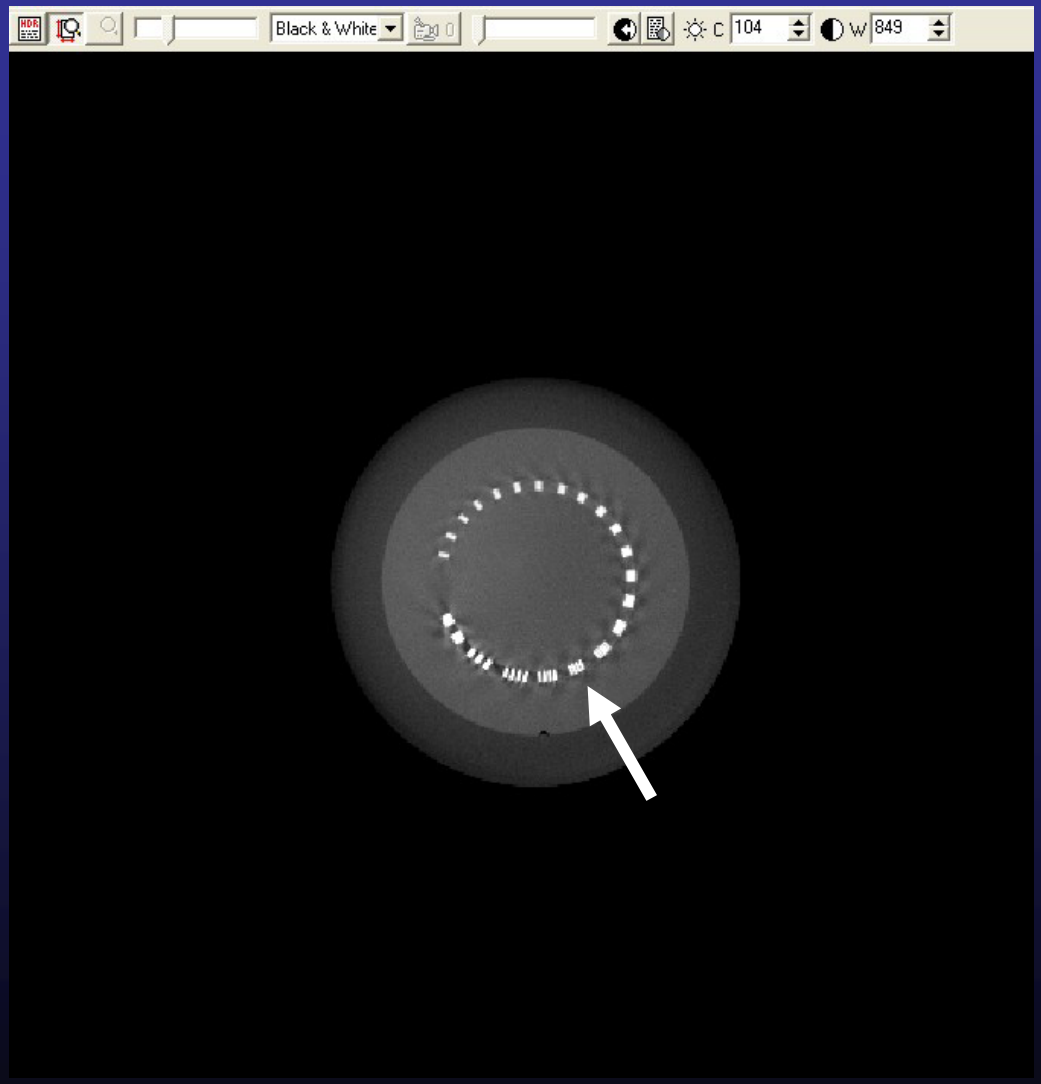
50-cm FOV

1% contrast is <u>barely</u> visible

$CBCTDI_w$ = 5.4cGy



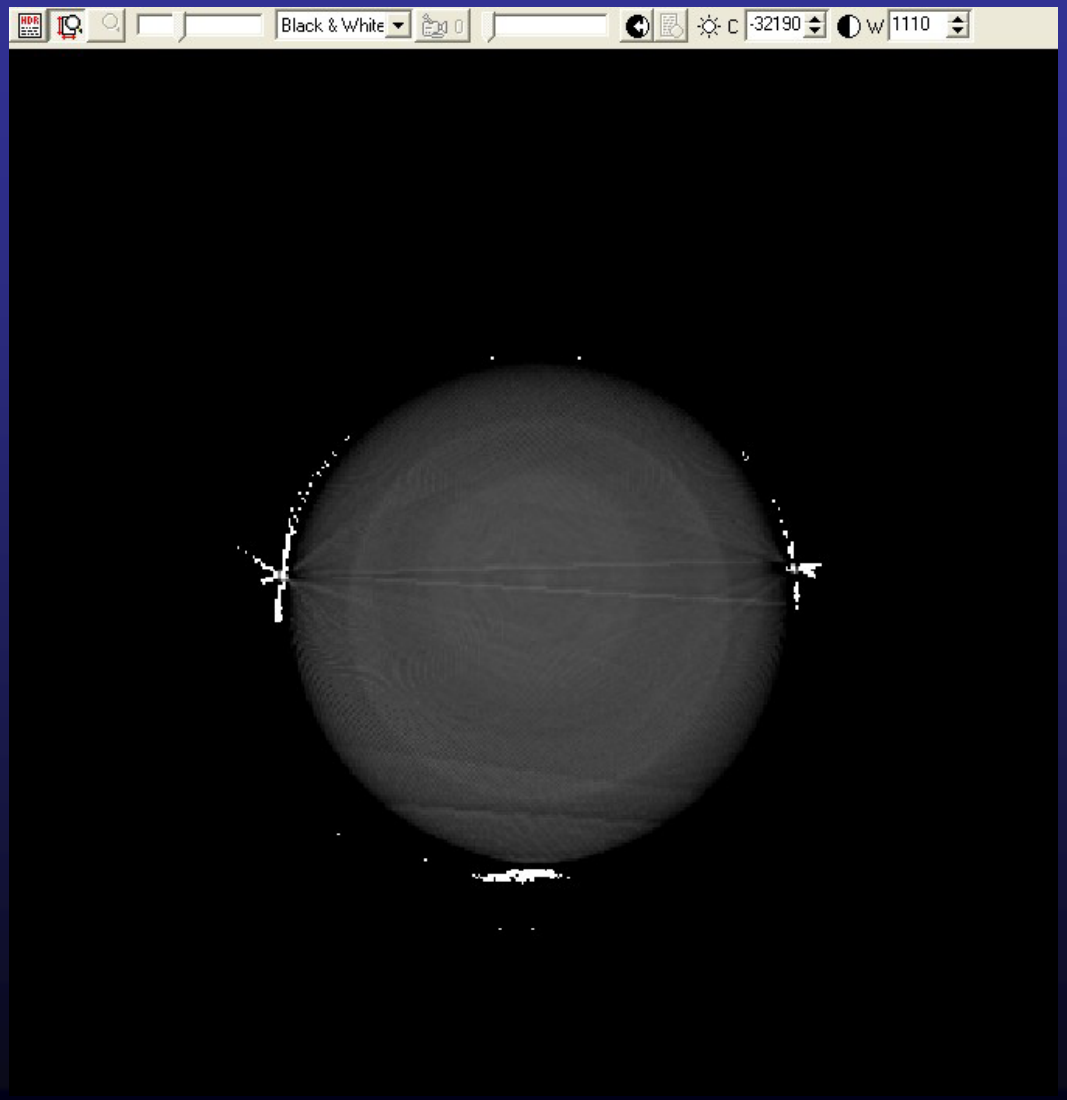
OBI: Half-Fan Mode



Resolution limit:
5 lp/cm

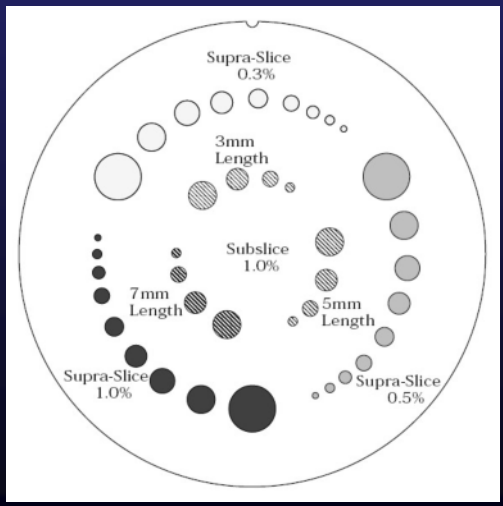
$CBCTDI_w$ = 5.4cGy

XVI: Pelvis protocol



None are visible

$CBCTDI_w$ = 2.4cGy

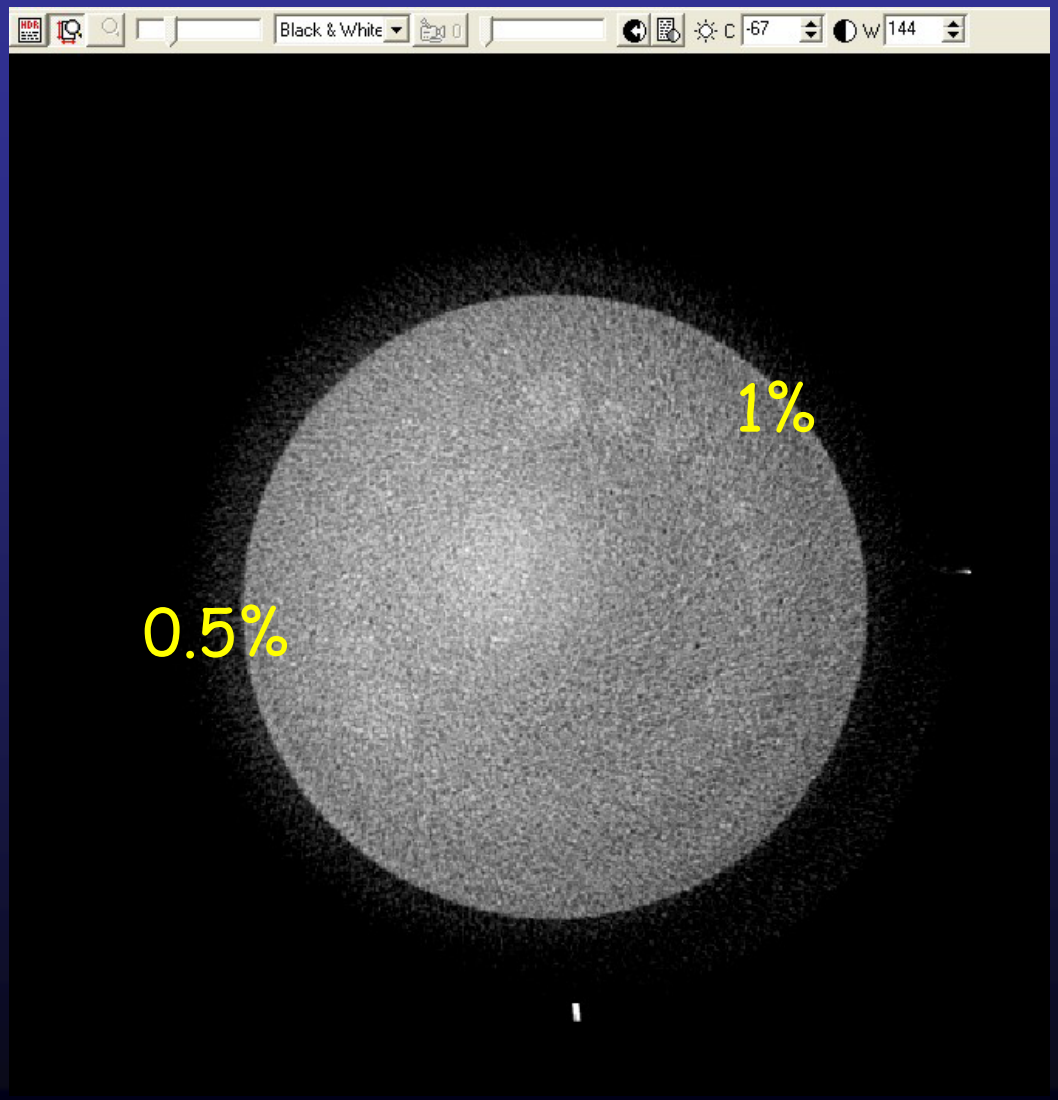


XVI: Pelvis protocol

Resolution limit:
4 lp/cm

$CBCTDI_w$ = 2.4cGy

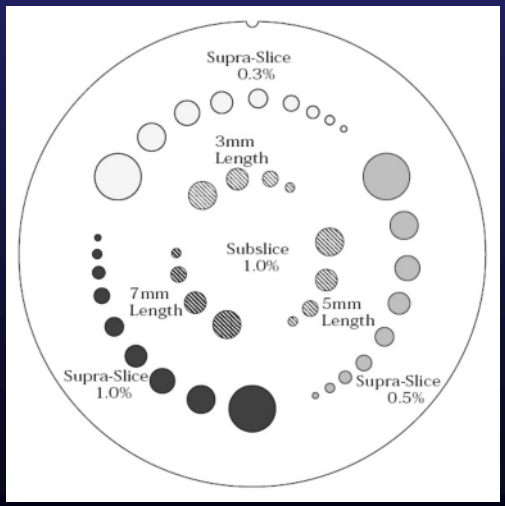
OBI: Half-Fan Mode



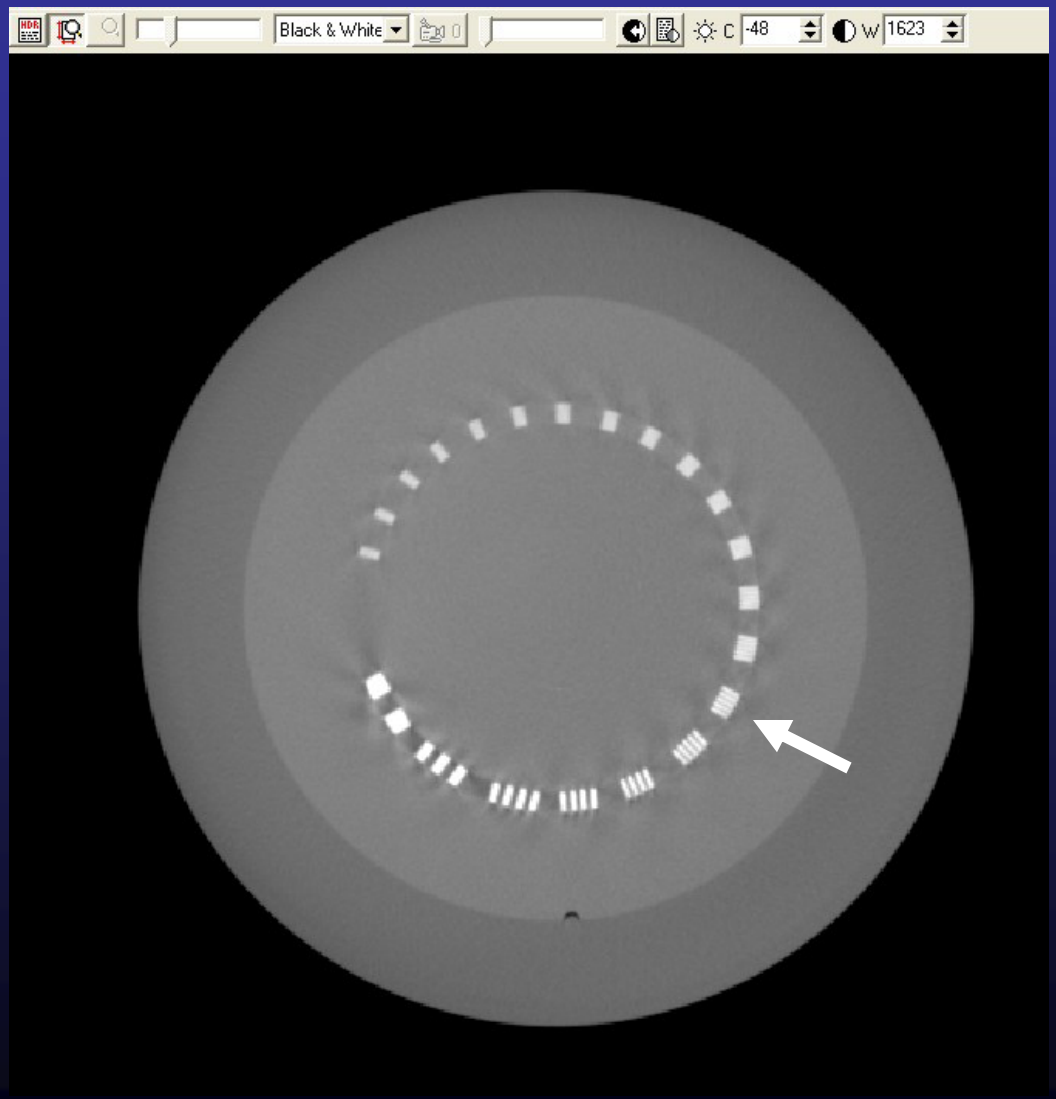
25-cm FOV

1% & 0.5% contrasts are visible

$CBCTDI_w$ = 5.4cGy



OBI: Half-Fan Mode

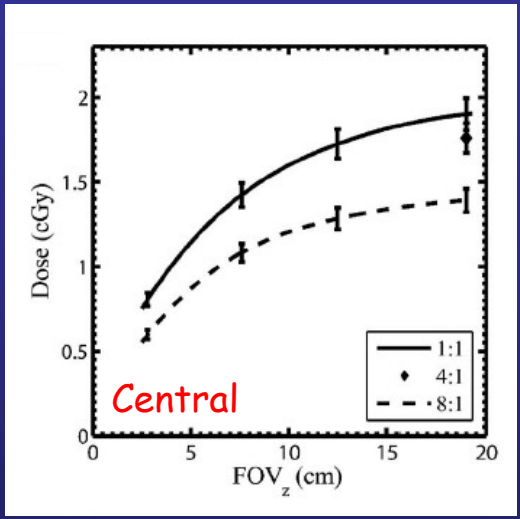


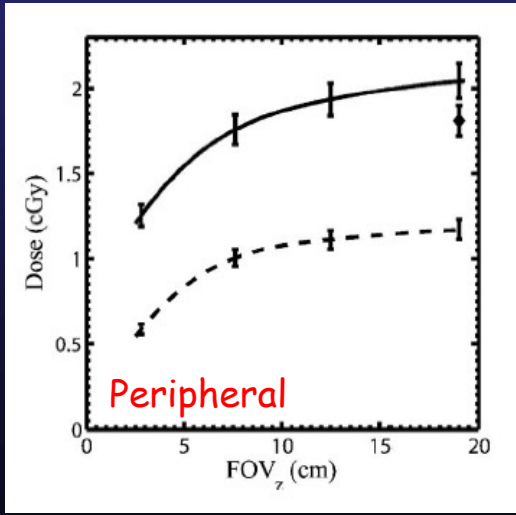
25-cm FOV

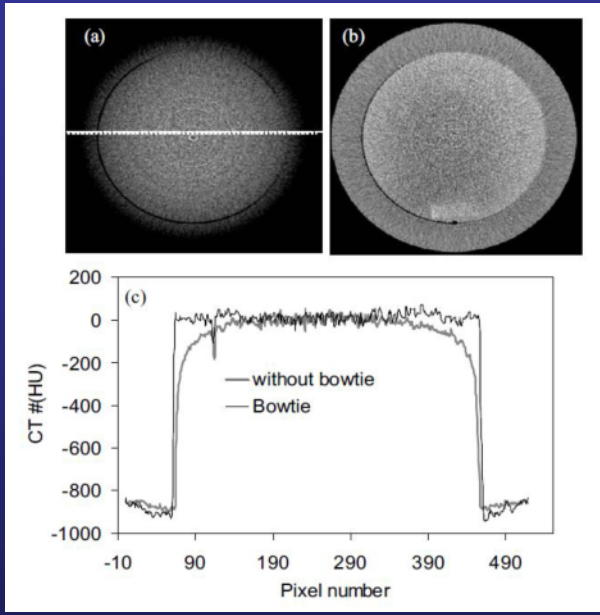
Resolution limit:
7 lp/cm

$CBCTDI_w$ = 5.4cGy

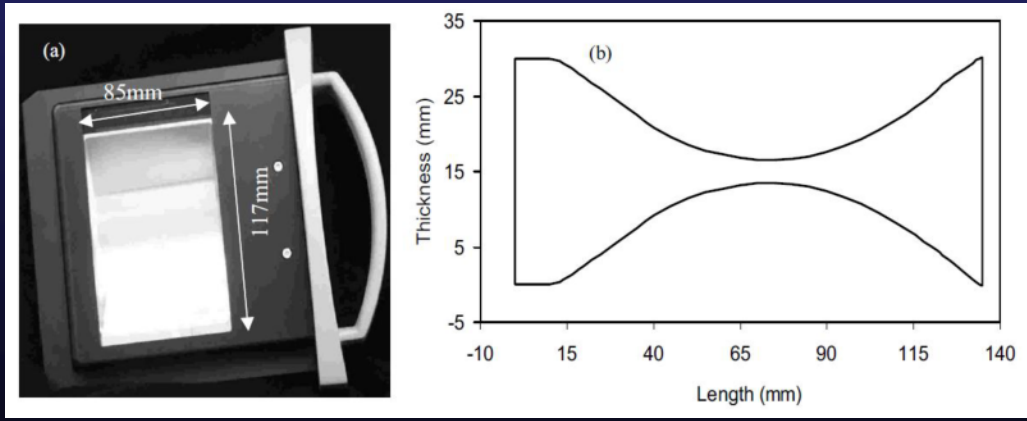
Bow-Tie filter for XVI®







Mail *et al.*, Med Phys 2009;36:22-32



Graham *et al.*, Med Phys 2007;34:2691-2703

CBCT QA

- Can be broken down to:
  - Mechanical Safety & Functionality
  - Geometric & Registration Accuracy
  - Image Quality
  - Beam Quality & Dose (or Kerma)

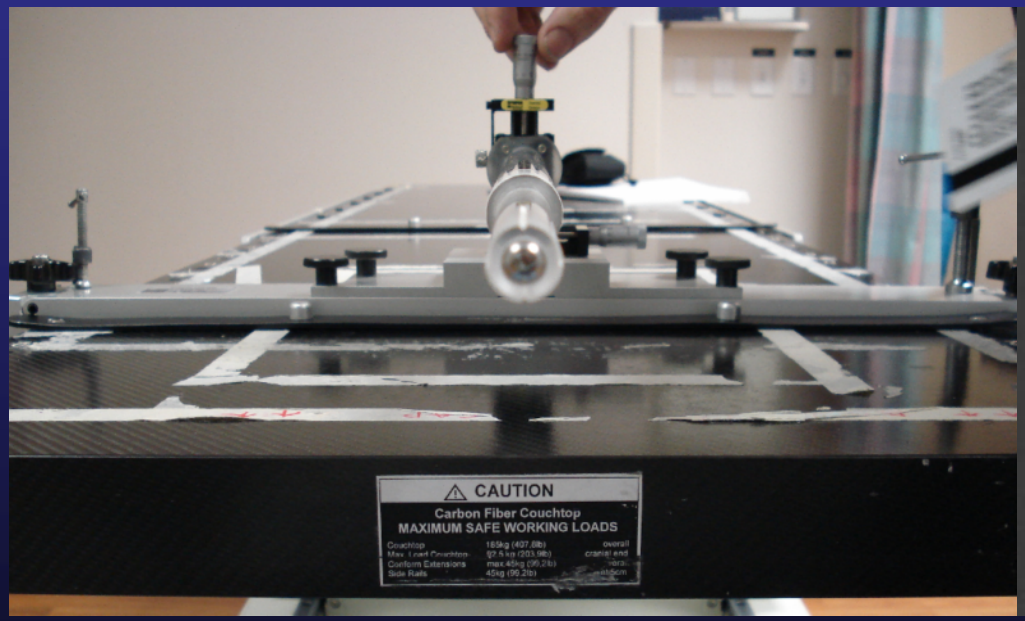
Safety & Functionality

- Similar to what is in the acceptance documents:
  - X-ray warm-up
  - All system interlocks
  - All system touch-guards
  - All warning lights

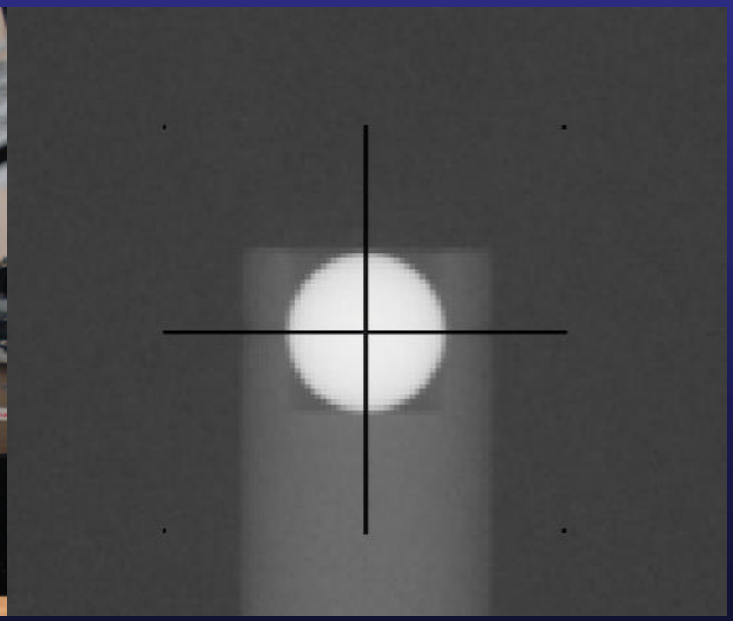
- Comprehensive list can be found in:
  - XVI: Lehmann *et al.*, J App Clin Med Phys 2007;8:21-36
  - OBI: Yoo *et al.*, Med Phys 2006;33:4431-4447

Geometric Accuracy

- Three isocenters to characterize:
  - Mechanical, MV, KV isocenters

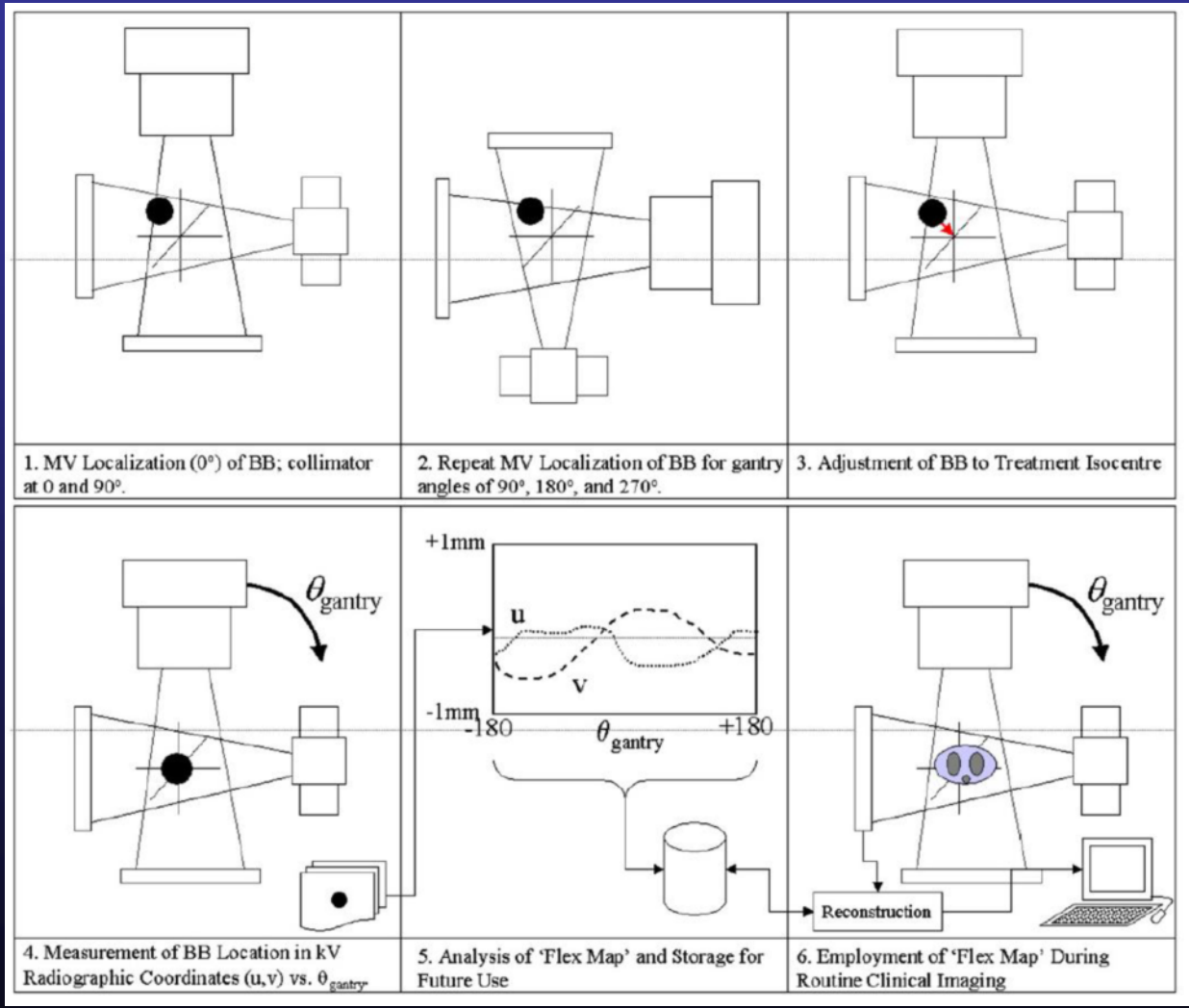


Elekta XVI®



Lehmann *et al.*, J App Clin Med Phys 2007;8:21-36

Geometric Accuracy



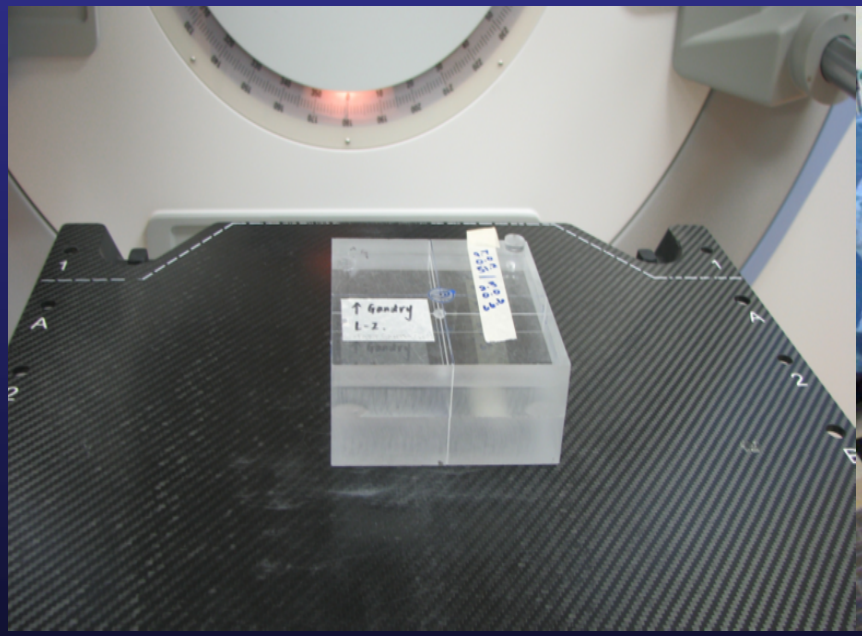
For XVI, the reconstruction software digitally corrects for the flex motions.

For OBI, the flex motions are compensated for by servos in the robotic arms.

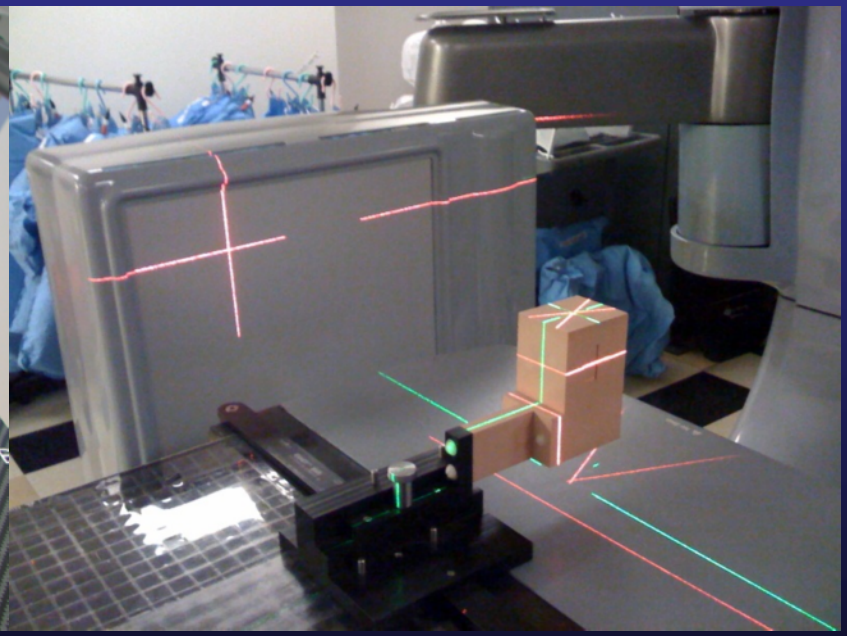
Bissonnette *et al.*, Red J 2008;71:S57-S61

Geometric Accuracy

- Typical phantoms used for daily geometry & registration check
- This type of phantom can be used to check both radiographic and 3D image geometric accuracies



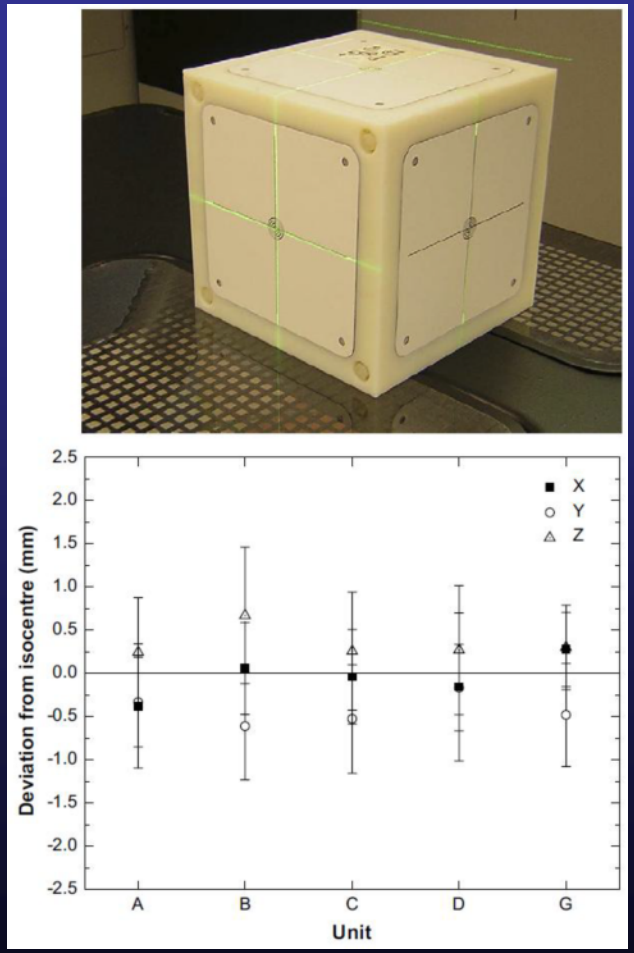
Elekta XVI®



Varian OBI®

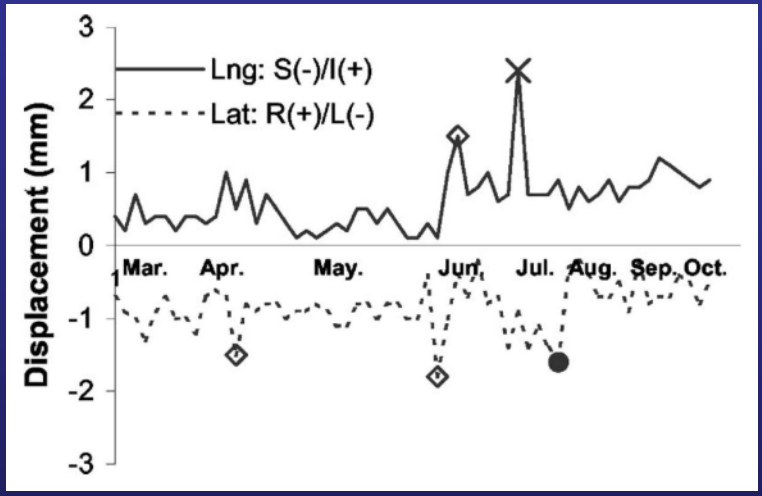
Geometric Accuracy

Elekta XVI®



Bissonnette *et al.*, Red J 2008;71:S57-S61

Varian OBI®

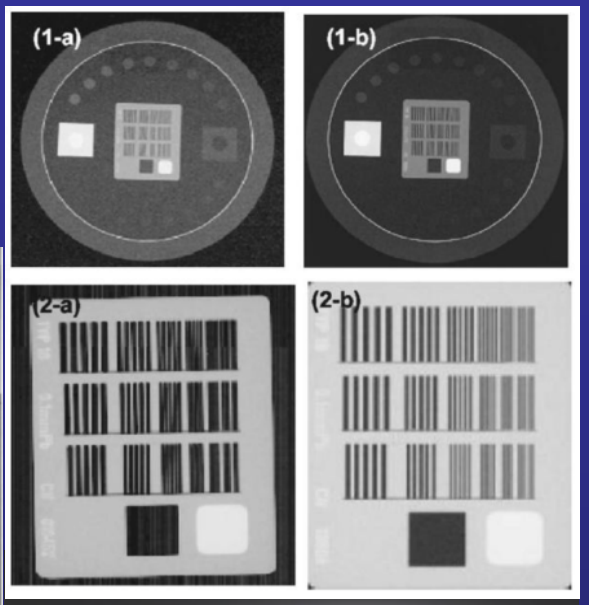


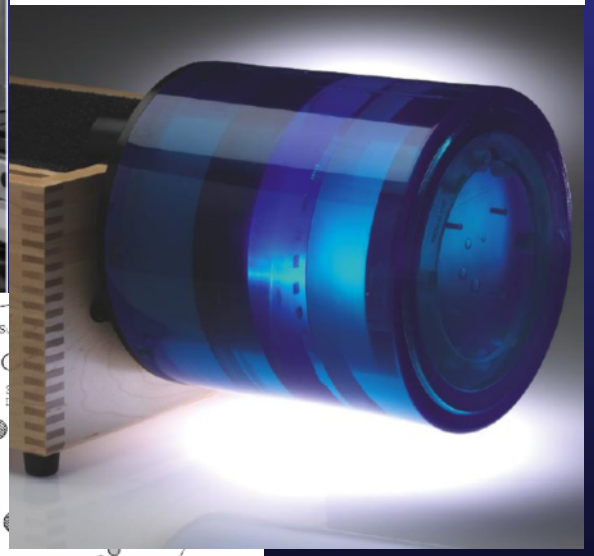
Yoo *et al.*, Med Phys 2006;33:4431-4447

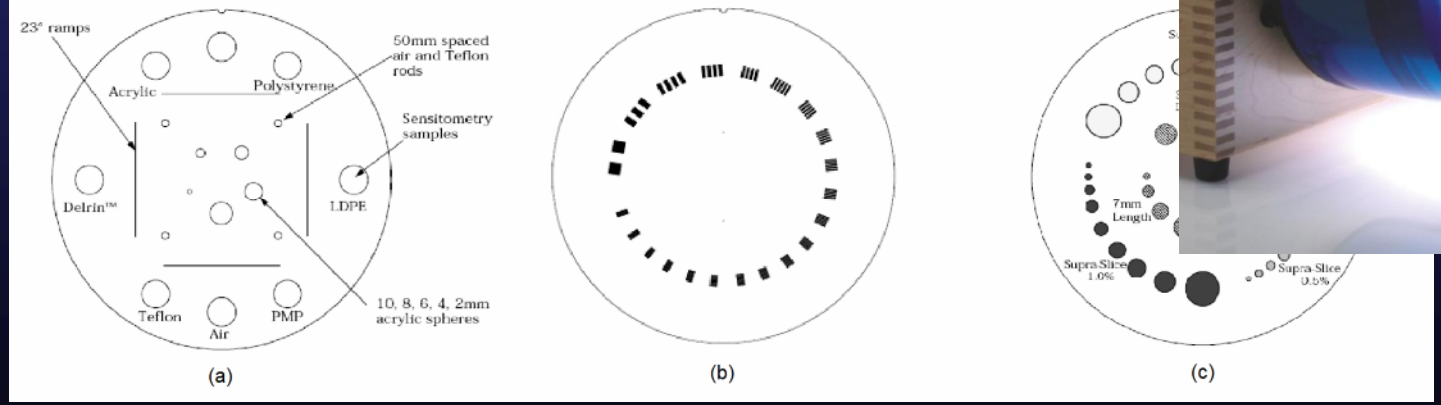
For XVI, mean ± sd ~ 1.0 ± 0.85 mm

For OBI, mean ± sd ~ 0.8 ± 0.4 mm

Image Quality







Kamath *et al.*, Med Phys 2009 (in revision)

Image Quality

- Topics to include:
  - HU linearity, uniformity, noise, CNR, etc.
  - Contrast resolution
  - Spatial resolution
  - Slice thickness accuracy

		Full fan	Half fan
	ExpectedHU	AverageHU±SD	AverageHU±SD
Air	−1000	−1023±1.8	−1023±1.9
PMP	−200	−189±8.2	−193±10.4
LDPE	−100	−94±3.6	−99±11.0
Polystyrene	−35	−39±5.2	−44±13.8
Acrylic	120	128±5.8	128±13.9
Delrin	340	349±13.4	343±18.0
Teflon	990	970±7.3	964±20.4

Yoo *et al.*, Med Phys 2006;33:4431-4447

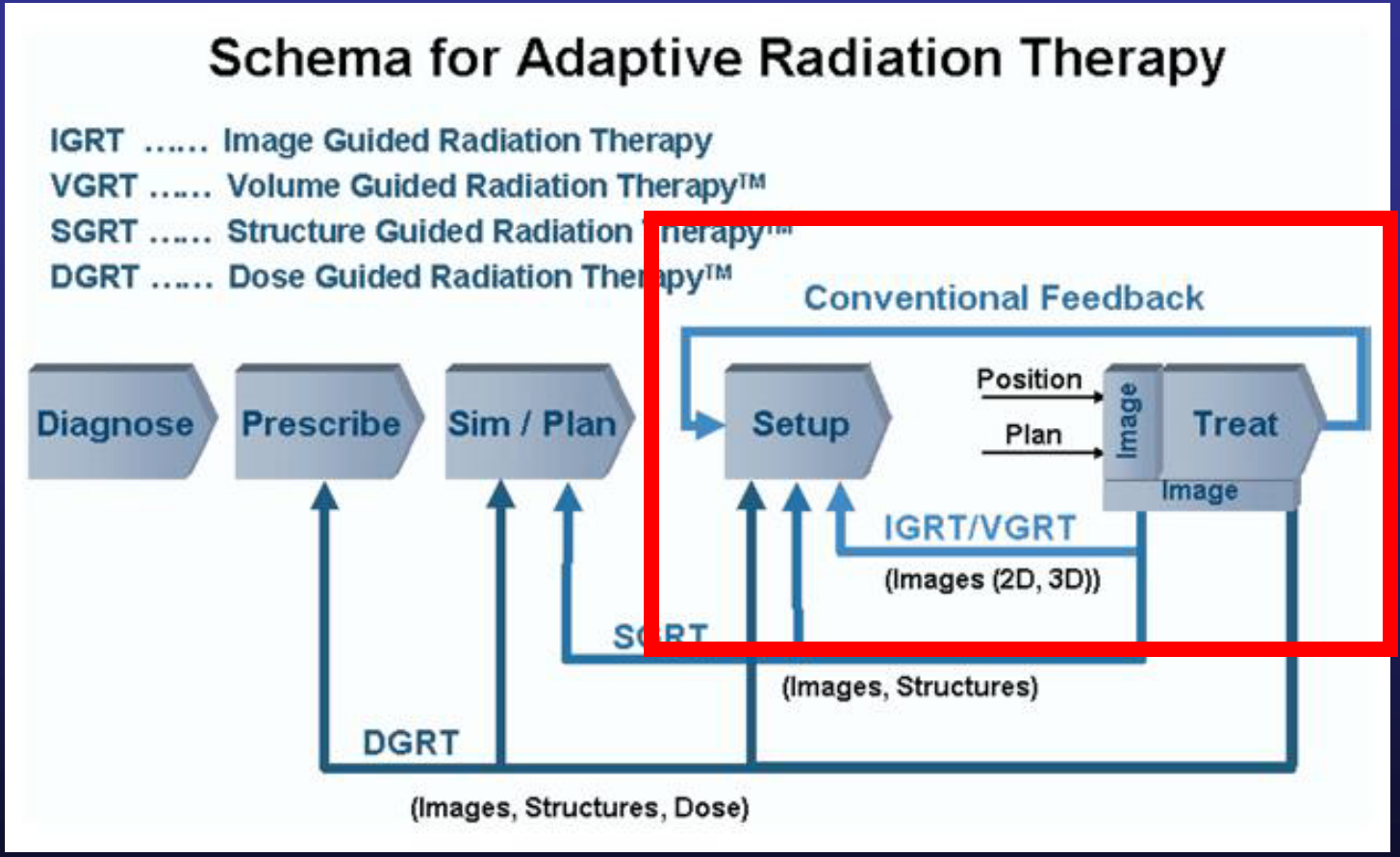
OBI manufacturer recommendation: ± 40 HU

Beam Quality & Dose

- Set baseline and measure:
  - Narrow-Beam HVL (mm-Al) for each kVp
  - Air-Kerma measurements with an ion chamber

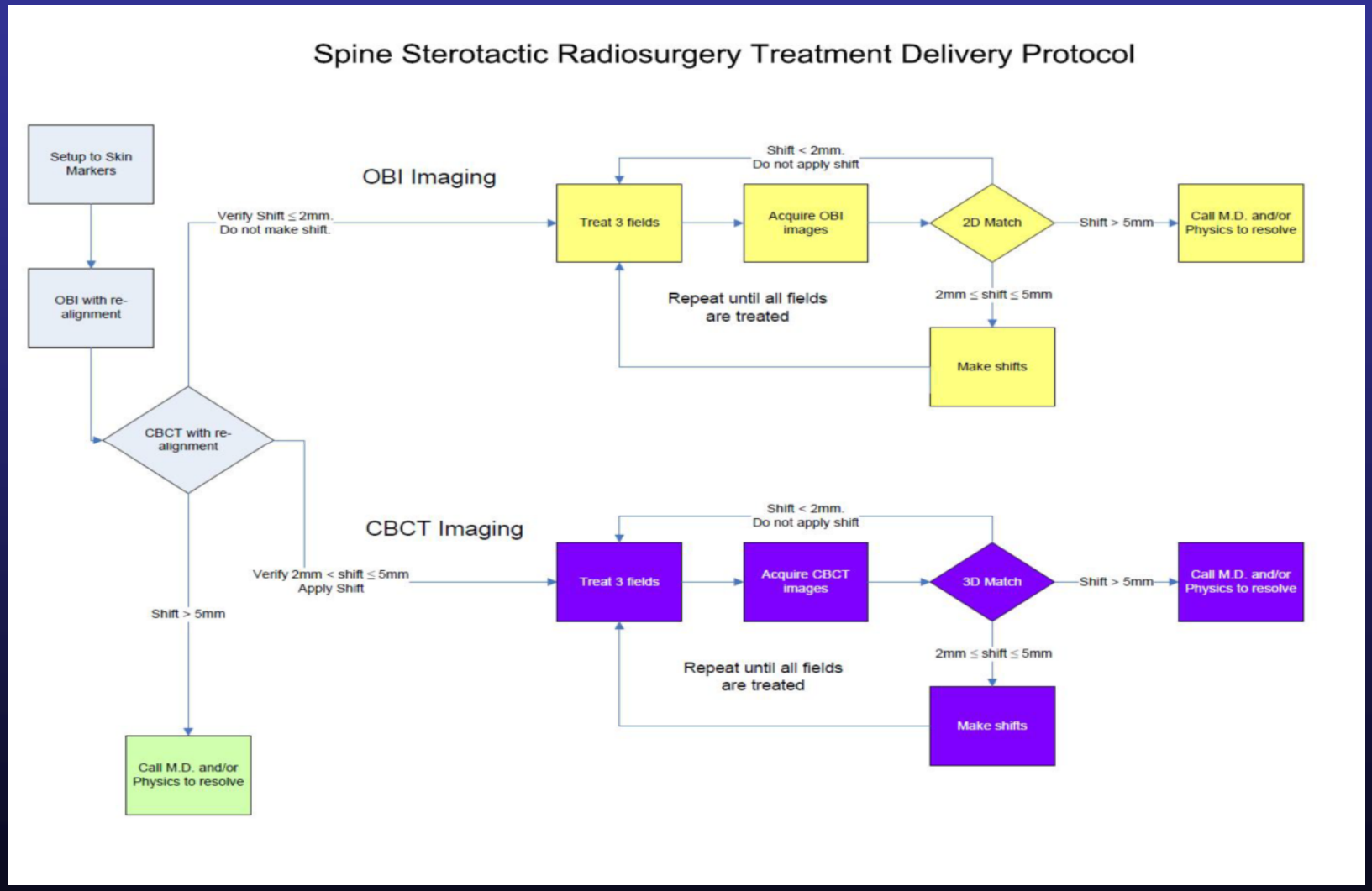
Machine	XVI		OBI			
X-ray Energy	100 kVp	120 kVp	100 kVp	125 kVp		
Filter	No Filter		No Filter	No Filter	Half Bow Tie	Full Bow Tie
HVL (mm-Al)	6.0	7.0	3.5	4.6	5.7	5.7

CBCT current/future use



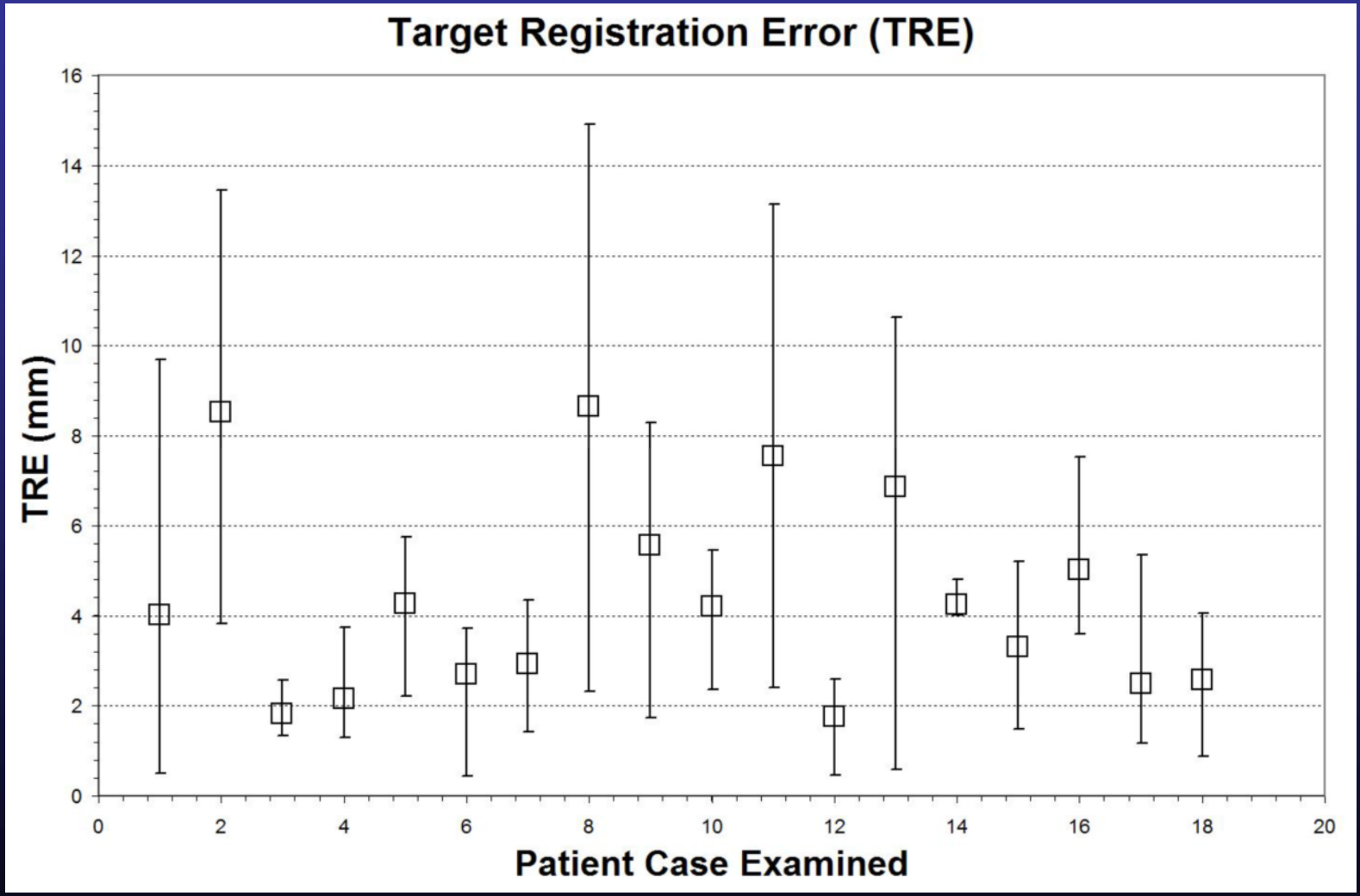
Amies *et al.*, Med Dosim 2006;31:12-19

CBCT current/future use



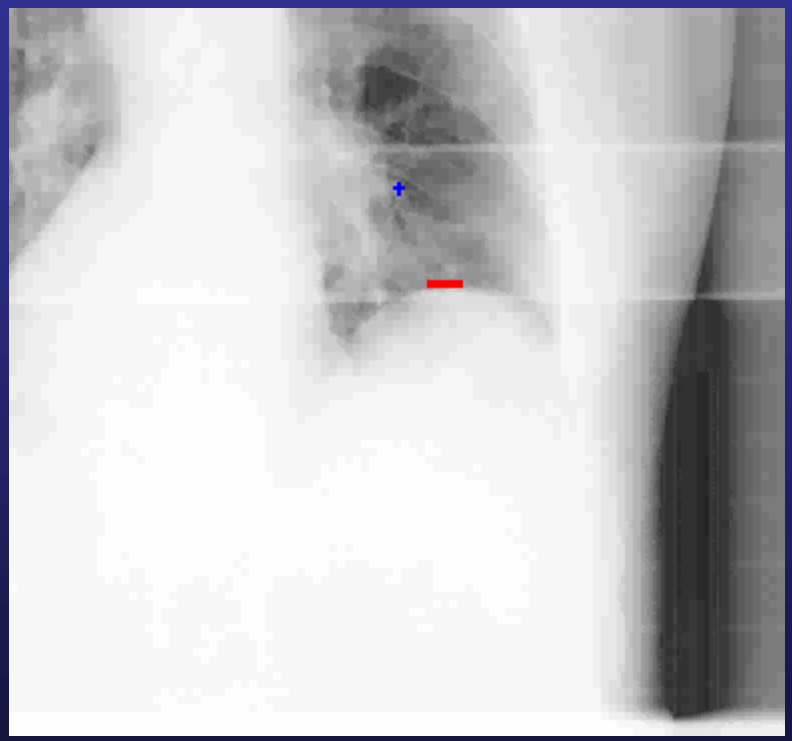
Spine-SBRT protocol implemented at UCSD

TRE based on bony matching



Courtesy: Mr Will Whartenby

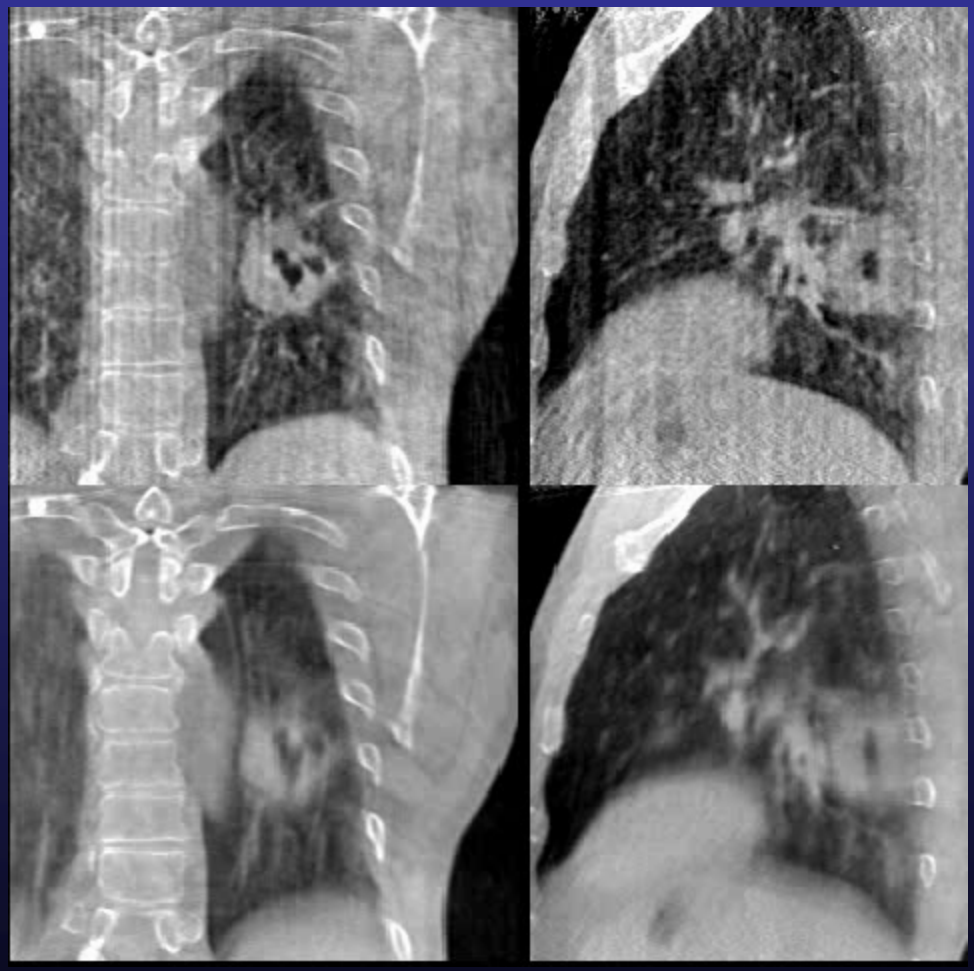
CBCT current/future use



Courtesy: Dr Laura Cervino

Currently, cannot display the PTV contour in the fluoroscopy imaging

4D-CBCT



Projections sorted based on internal lung surrogates (eg, diaphragm)

This technique has been applied to lung SBRT patient setup (margin = 5.8-10.5mm for 2-28mm peak-to-peak amplitude)

Projections can also be sorted by the RPM signal (Biederer et al., Red J 2009;73:919-926)

Image courtesy: Dr Jan-Jakob Sonke

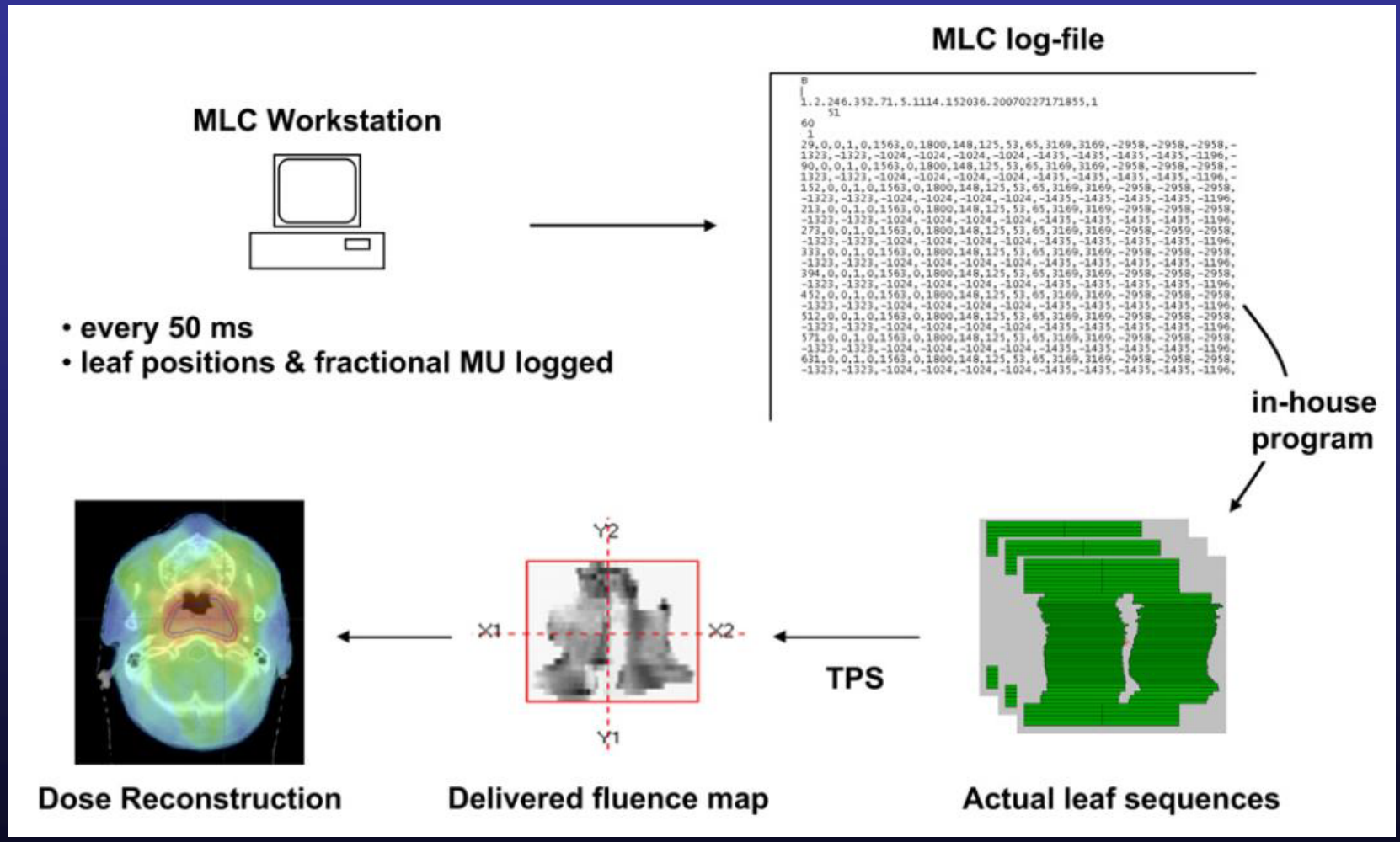
Cone-Beam Tomosynthesis

- Digital Tomosynthesis (DTS):
  - DTS can be reconstructed from limited-angle CBCT imaging
  - Has high spatial resolution in viewing plane, but limited effective slicethickness resolution due to the narrow scanning angle
  - Fraction of dose delivered to patients
  - Has high correlation with CBCT setup correction for prostate IGRT: ~ 0.8 – 0.9

Matching	2D and CBCT	2D and coronal DTS	2D and sagittal DTS	CBCT and coronal DTS	CBCT and sagittal DTS
Bony anatomy					
Lateral (mm)	1.1 ± 1.1	1.1 ± 1.0	0.6 ± 1.1	0.3 ± 0.6	0.7 ± 0.8
Longitudinal (mm)	0.1 ± 1.3	0.1 ± 1.1	0.3 ± 1.2	0.3 ± 0.6	0.3 ± 0.6
Vertical (mm)	0.9 ± 0.9	0.9 ± 1.0	1.2 ± 0.9	0.5 ± 0.7	0.7 ± 0.6
Pitch (°)	0.23 ± 0.34	0.20 ± 0.33	0.27 ± 0.36	0.04 ± 0.15	0.06 ± 0.18
Roll (°)	NA	NA	NA	0.40 ± 0.42	0.41 ± 0.48
Yaw (°)	0.53 ± 0.40	0.53 ± 0.47	0.54 ± 0.47	0.30 ± 0.40	0.25 ± 0.36
Vector (°)	2.1 ± 1.1	2.0 ± 1.1	2.0 ± 1.2	1.1 ± 0.8	1.4 ± 0.7
Soft tissue					
Lateral (mm)				0.8 ± 0.7	1.5 ± 1.4
Longitudinal (mm)				0.6 ± 0.6	0.9 ± 0.9
Vertical (mm)				1.1 ± 1.2	1.7 ± 1.7
Vector (°)				1.8 ± 1.1	2.9 ± 1.7

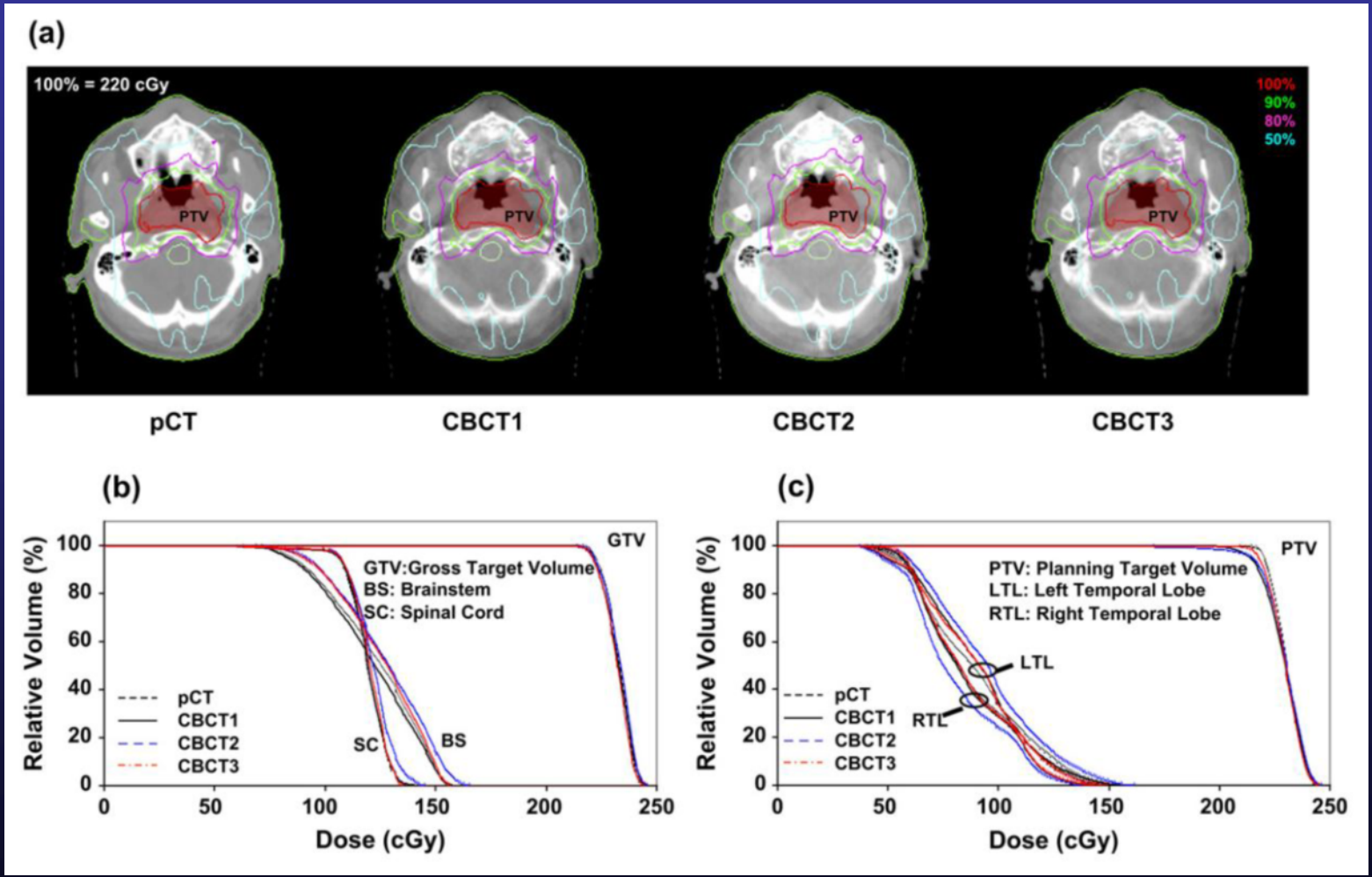
Yoo *et al.*, Red J 2009;73:296-305

Dose reconstruction using dynalog files



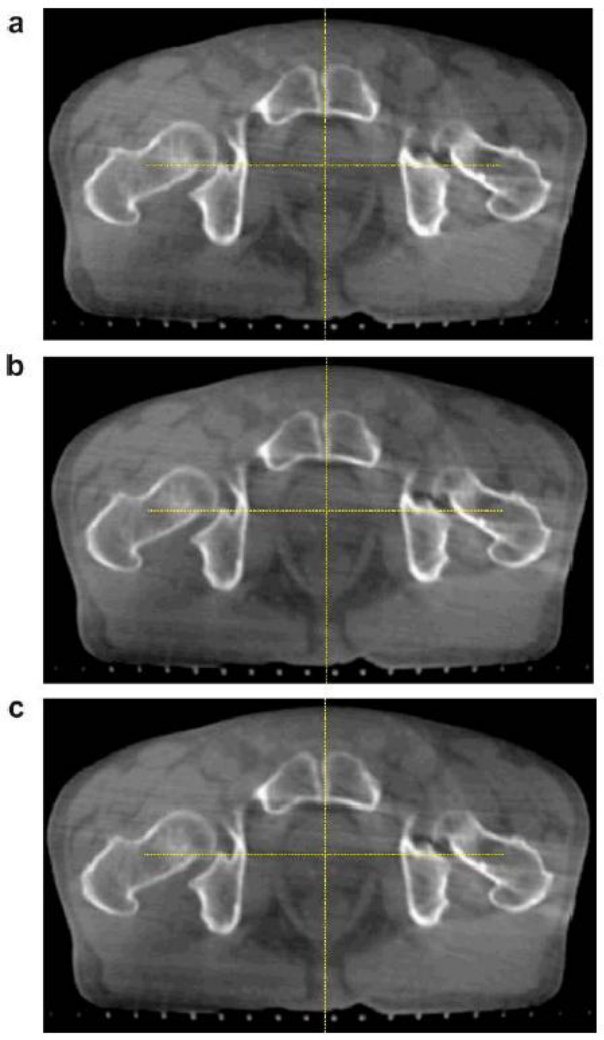
Lee *et al.*, Red J 2008;70:634-644

Dose reconstruction using dynalog files



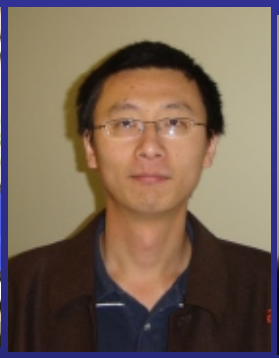
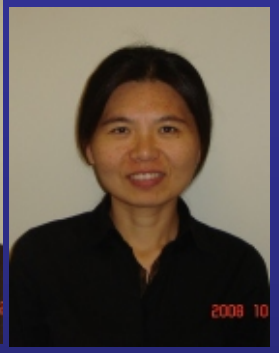
Lee *et al.*, Red J 2008;70:634-644

CBCT during VMAT



kV CBCT axial images of a prostate cancer patient: (a) immediately before treatment after registration, (b) during VMAT delivery, and (c) immediately after treatment. The cross lines indicate the isocenter.
Nakagawa *et al.* Green J. 2009;422-423

Thank you!!

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