Patient Dosimetry in IGRT

Joint ICTP-IAEA International Workshop on the Implementation of Image Guided Radiotherapy (IGRT)

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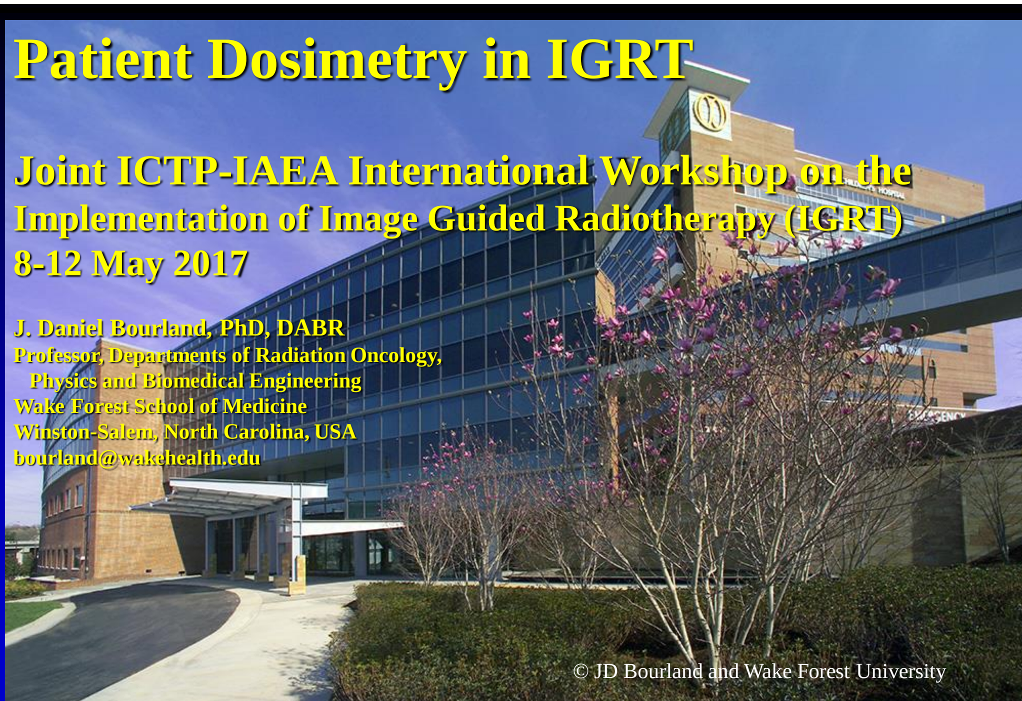


Outline

- kV IGRT Technologies Dose
- MV CBCT Dose
- IGRT Dose Reduction
- IGRT Dose Avoidance
- IGRT Dose Records
- Summary

Patient Imaging Dose From IGRT

Why do we care?

- ALARA – As Low As Readily Achievable
- Must be benefit of dose with minimal risk
  “Image Gently” – most quality for least dose
- Pediatric patients, other sensitive populations
- Medical devices (implanted pacemakers, etc)
- Note: CBCT FOV likely larger than SBRT fields

Patient Imaging Dose From IGRT

Important questions

- Does imaging dose matter relative to radiation treatment dose?
- What is its distribution?
- Can we compute it correctly?
- How shall we record it and does it add to therapeutic benefit?

CT Dose in kV Diagnostic Imaging

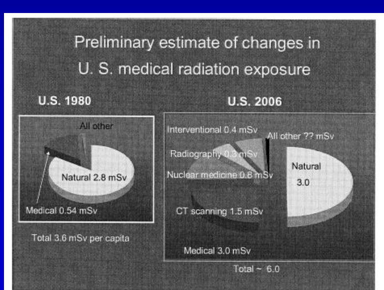
- A great debate in CT imaging – how much dose is acceptable, and how to measure it
- Numerous dose representations, and diagnostic dosimetry is different from therapy dosimetry – but it should NOT be different – it is all dose
- Main concern is the large number of individuals that receive CT dose – dose is relatively low, but to a large percentage of the population

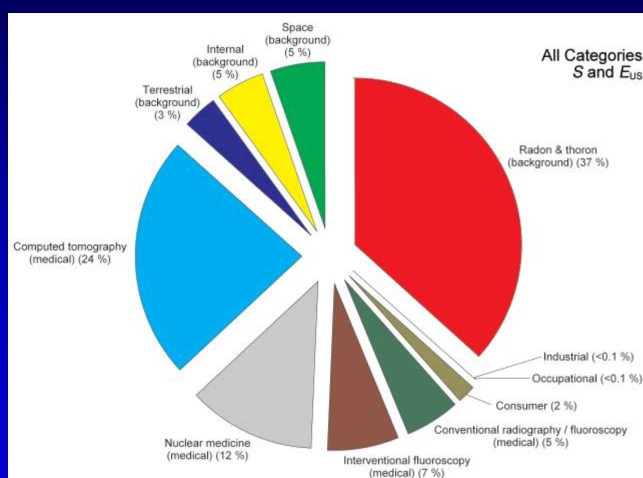
“Population Dose” Risk ~ 0.05 deaths/Sv-person

MEDICAL RADIATION EXPOSURE IN THE U.S. IN 2006: PRELIMINARY RESULTS

Fred A. Mettler, Jr.,* Bruce R. Thomadsen,† Mythreyi Bhargavan,‡ Debbie B. Gilley,§ Joel E. Gray,** Jill A. Lipoti,†† John McCrohan,‡‡ Terry T. Yoshizumi,§§ and Mahadevappa Mahesh***

- NCRP Report 160





Deterministic Radiation-Induced Morbidity
Dose Thresholds and Time of Onset

Effects	Threshold	Time of Onset
Early transient erythema	2000 mGy	2–24 h
Temporary epilation	3000 mGy	1.5 weeks
Main erythema	6000 mGy	3 weeks
Permanent epilation	7000 mGy	3 weeks
Dermal necrosis	15,000 mGy	>52 weeks
Eye lens opacity (detectable)	>1000 mGy	>5 years
Cataract (debilitating)	>5000 mGy	>5 years

Murphy MJ et al. The management of imaging dose during imaged-guided radiotherapy: Report of the AAPM Task Group 75. Med. Phys. 34(10), October 2007.

Dose Metrics Diagnostic CT

- Volume CTDI ($CTDI_{vol}$)
- Dose Length Product (DLP)
- Effective Dose (E)

$$E = \sum_T w_T H_T$$

Volume CTDI ($CTDI_{vol}$): The CTDI variant that is currently of most relevance is the Volume CTDI ($CTDI_{vol}$). This parameter accounts for gaps or overlaps between the x-ray beams from consecutive rotations of the x-ray source and variations in dose across the FOV. The $CTDI_{vol}$ provides a single parameter, based on a directly and easily measured quantity, which describes the radiation delivered to the scan volume for a standardized (CTDI) phantom[13]. The SI units are milli-Gray (mGy). $CTDI_{vol}$ is a useful indicator of the radiation output for a specific exam protocol, because it takes into account protocol-specific information such as pitch. However, it is important to realize that $CTDI_{vol}$ is not a direct measurement of dose; it is a standardized measure of radiation output in the CT environment[14].

Dose Length Product (DLP): To better represent the overall energy delivered by a given scan protocol, the $CTDI_{vol}$ can be integrated along the scan length to compute the Dose-Length Product (DLP)[7], where the DLP (in mGy-cm) is equal to $CTDI_{vol}$ (in mGy) times scan length (in cm). The DLP reflects the integrated radiation output (and thus the potential biological effect) attributable to the complete scan acquisition. Thus, an abdomen-only CT exam might have the same $CTDI_{vol}$ as an abdomen/pelvis CT exam, but the latter exam would have a greater DLP, proportional to the greater z-extent of the scan volume.

Effective Dose (E)—Effective dose, E, is not a measurement of dose, but rather a concept that reflects the stochastic risk (e.g. cancer induction) from an exposure to ionizing radiation[15, 16]. It is typically expressed in the units of milli-Sieverts. Effective dose reflects radiation detriment averaged over gender and age and its use has several limitations when applied to medical populations[15–18]. In particular, it uses a mathematical model for a "standard" body in its calculation[19] and is hence not an appropriate risk indicator for any one individual. However, it does facilitate the comparison of biologic effect between diagnostic exams of different types or having different acquisition parameters[15, 16]. By comparing patient effective dose to background radiation dose from natural sources, which in the U.S. averages 3 mSv per year with a range across the U.S. from 1–10 mSv[2], patients and their families are better able to put the risk associated with medical doses into perspective.

McCollough et al., *Radiol Clin North Am*. 2009 January ; 47(1): 27–40.

AAPM Report No. 111 (Non-CTDI)

AAPM REPORT NO. 111

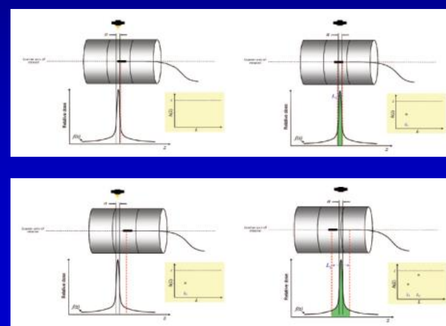
Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography

A New Measurement Paradigm Based on a Unified Theory for Axial, Helical, Fan-Beam, and Cone-Beam Scanning With or Without Longitudinal Translation of the Patient Table

Report of AAPM Task Group 111: The Future of CT Dosimetry

February 2010

$$D_L(z)=\frac{1}{b}f(z)\otimes\Pi(z/L)=\frac{1}{b}\int_{-L/2}^{L/2} f(z-z')\,dz'.$$



AAPM TG-61: X-ray Dosimetry

AAPM protocol for 40–300 kV x-ray beam dosimetry in radiotherapy and radiobiology

Med. Phys. 28 (6), June 2001

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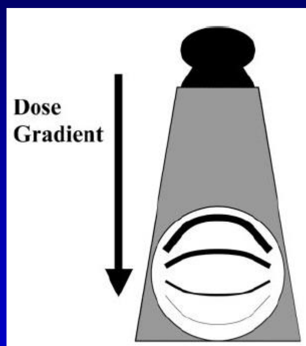
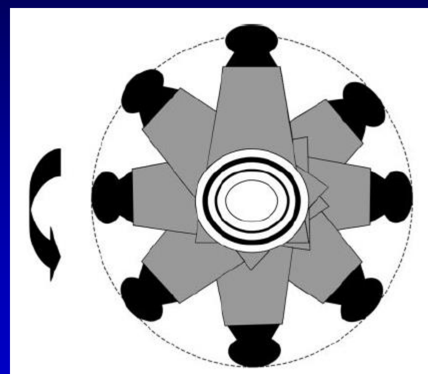
X-ray Dose Process in kV CT

Single beam



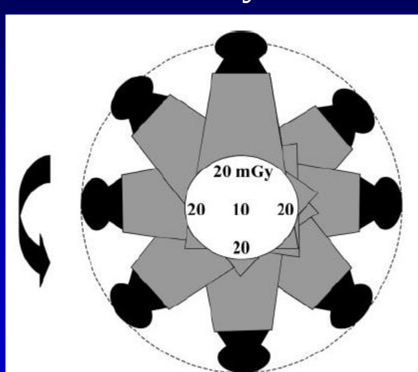
Multiple beams



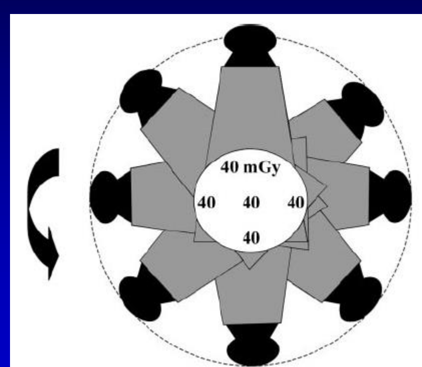
M McNitt-Gray, RadioGraphics 2002; 22:1541–1553.

X-ray Dose Process in kV CT

Body



Head

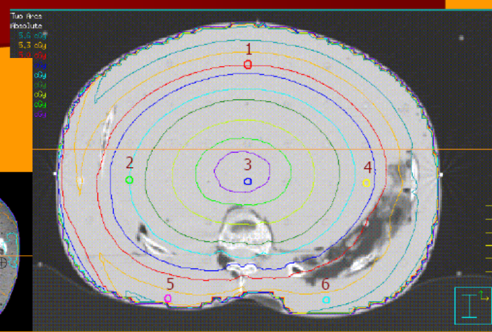


M McNitt-Gray, RadioGraphics 2002; 22:1541–1553.

kV CBCT Dose Calculations, First Done

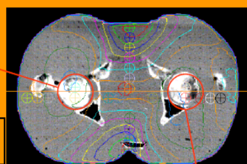
- Used Pinnacle RTP
- Bone corrections

Dose Calculations-Elekta XVI



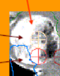
Dose to points in bone corrected by the ratios of bone/water mass energy absorption coefficients in table X of TG-61

Pt. 15
Pt. 14



Point	Computed Dose (cGy)	Corrected Dose (cGy)	% difference (after correction)
14	2.4	8.47	26.47
15	2.3	8.11	28.65
20	2.9	11.42	11.97
21	2.9	11.05	21.46

Pt. 21
Pt. 20



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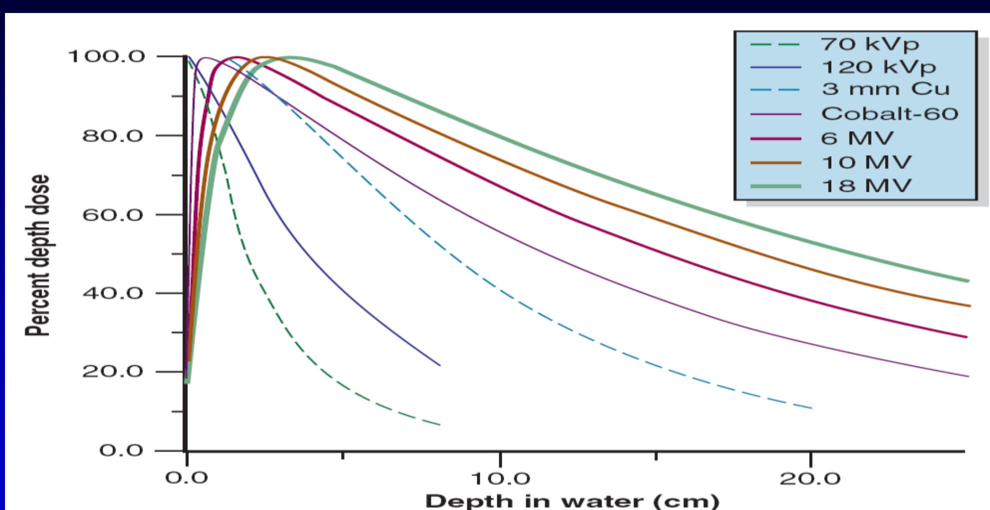
UNIVERSITY OF MINNESOTA

Alaei P. Review of the Doses from Cone Beam CT and Their Inclusion in the Treatment Planning https://www.medicaldosimetry.org/pub/39774274-2354-d714-51f0-8be87ec1b43b

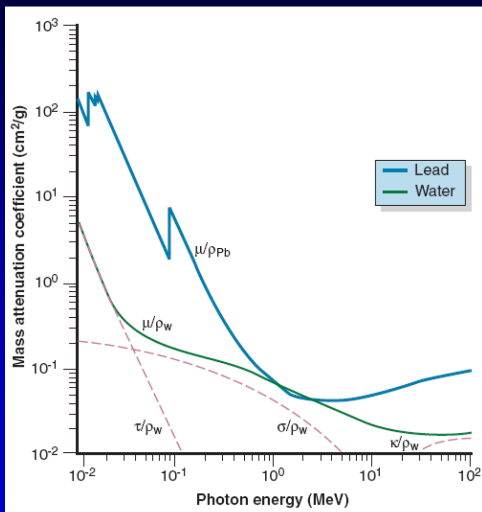
MV vs kV X-ray Percent Depth Dose

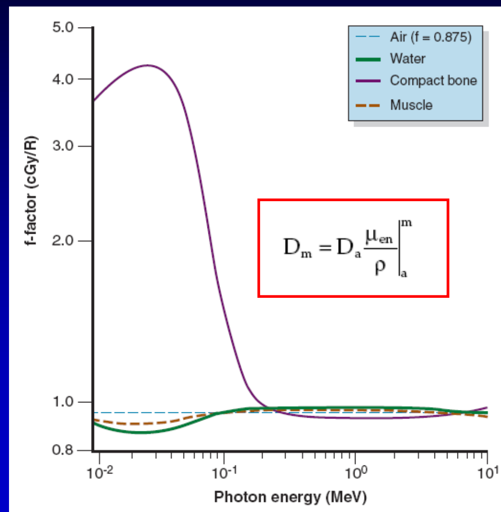


Bourland JD. "Radiation Oncology Physics," in Clinical Radiation Oncology, 3rd edition, Gunderson LL, and Tepper JE, WB Saunders Company, Philadelphia, 2012.

kV vs MV Imaging Dose

PE vs CE; higher Z → higher dose: Bone!

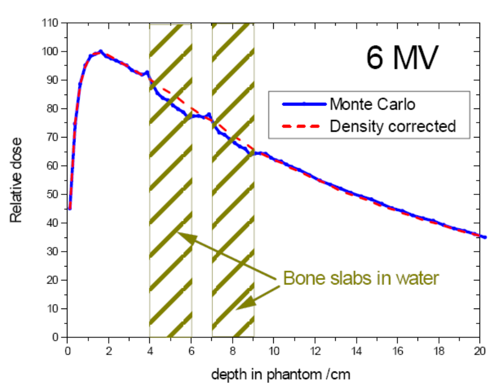


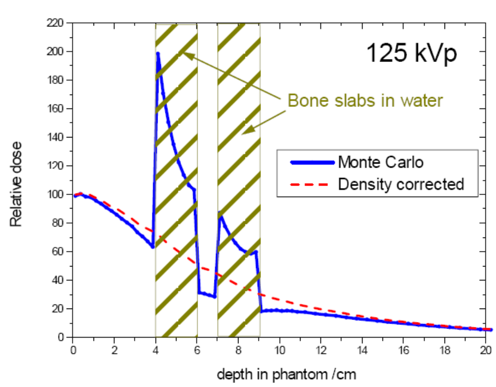


Bourland JD. "Radiation Oncology Physics," in Clinical Radiation Oncology, 3rd edition, Gunderson LL, and Tepper JE, WB Saunders Company, Philadelphia, 2012.

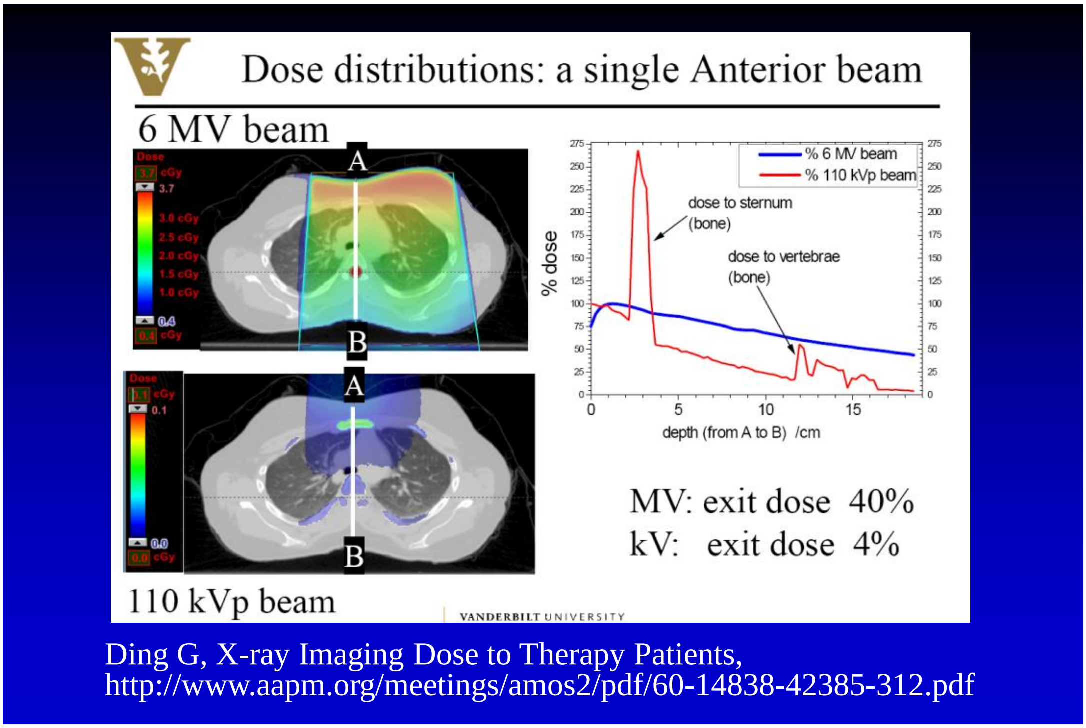
Dose dependency on medium for MV beam

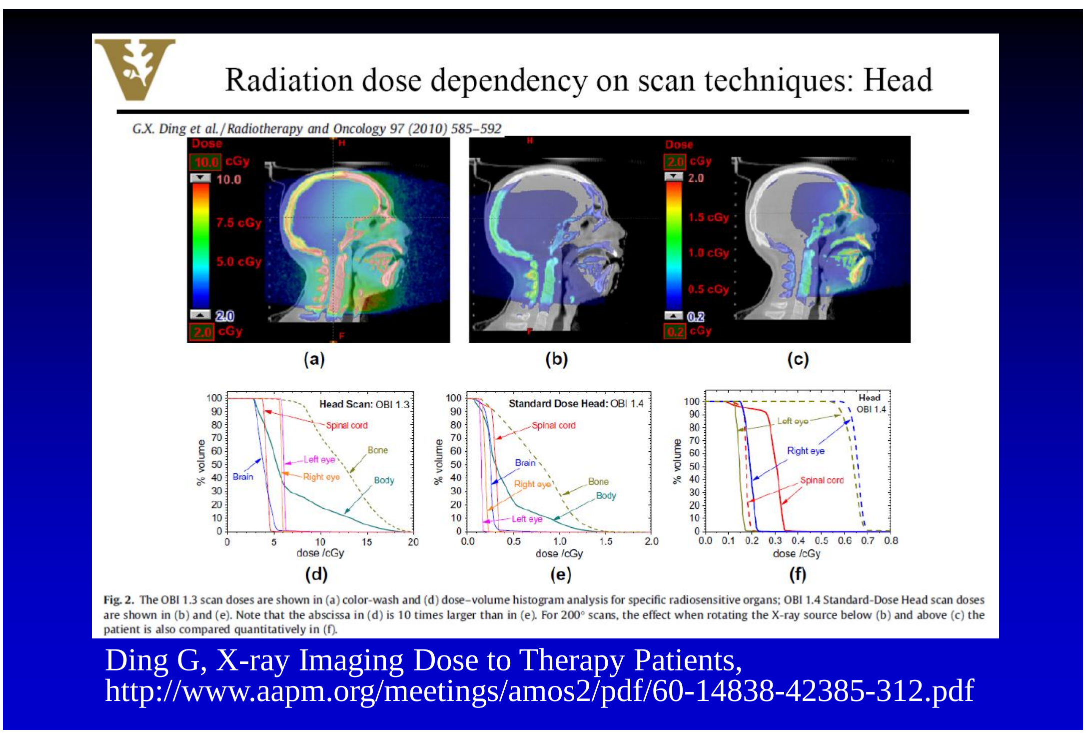
Single beam incident from right





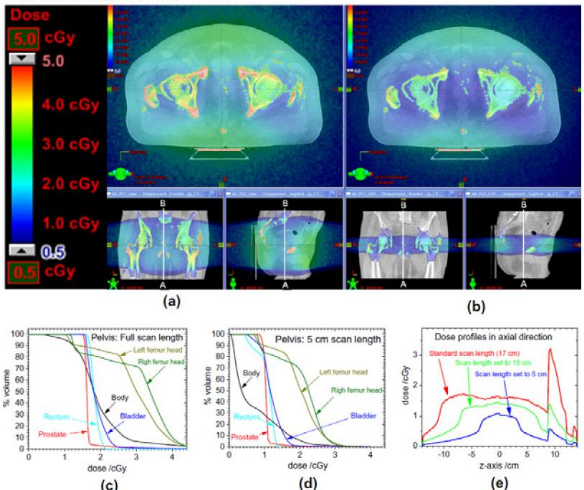
Ding G, X-ray Imaging Dose to Therapy Patients, http://www.aapm.org/meetings/amos2/pdf/60-14838-42385-312.pdf


Dose distributions: a single Anterior beam
6 MV beam
% 6 MV beam
% 110 kVp beam
dose to sternum (bone)
dose to vertebrae (bone)
% dose
depth (from A to B) /cm
MV: exit dose 40%
kV: exit dose 4%
110 kVp beam
VANDERBILT UNIVERSITY
Ding G, X-ray Imaging Dose to Therapy Patients,
http://www.aapm.org/meetings/amos2/pdf/60-14838-42385-312.pdf


Radiation dose dependency on scan techniques: Head
G.X. Ding et al. / Radiotherapy and Oncology 97 (2010) 585–592
(a)
(b)
(c)
Head Scan: OBI 1.3
Standard Dose Head: OBI 1.4
Spinal cord
Bone
Body
Brain
Left eye
Right eye
% volume
dose /cGy
(d)
(e)
(f)
Fig. 2. The OBI 1.3 scan doses are shown in (a) color-wash and (d) dose–volume histogram analysis for specific radiosensitive organs; OBI 1.4 Standard-Dose Head scan doses are shown in (b) and (e). Note that the abscissa in (d) is 10 times larger than in (e). For 200° scans, the effect when rotating the X-ray source below (b) and above (c) the patient is also compared quantitatively in (f).
Ding G, X-ray Imaging Dose to Therapy Patients,
http://www.aapm.org/meetings/amos2/pdf/60-14838-42385-312.pdf

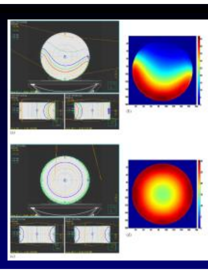
Radiation dose dependency on scanned length: Pelvis

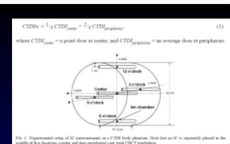
G.X. Ding et al. / Radiotherapy and Oncology 97 (2010) 585–592



Ding G, X-ray Imaging Dose to Therapy Patients,
http://www.aapm.org/meetings/amos2/pdf/60-14838-42385-312.pdf

kV dose estimates in 3D RTP





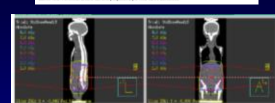
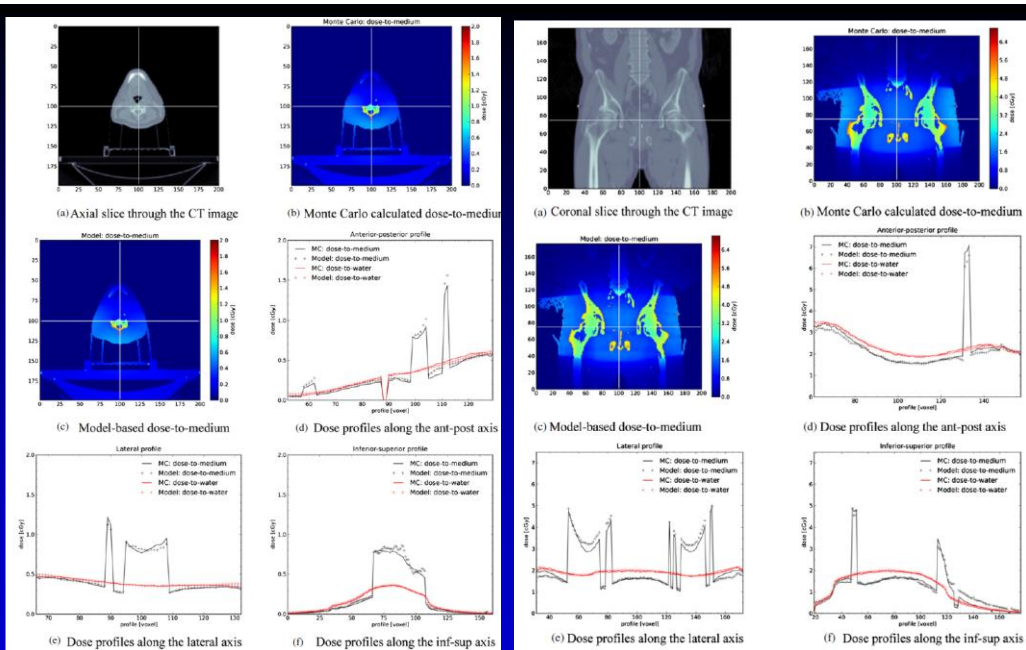


TABLE 2. Comparison of CTDI and weighted CTDI values among TPS dose calculations, ion chamber measurements and MC simulations.

	Pelvis Spotlight					Pelvis				
Location[b]	IC[a] Dose (cGy)	CCC Dose (cGy)	MC[a] Dose (cGy)	IC - CCC Diff. (cGy)	IC - CCC Diff. (%)	IC[a] Dose (cGy)	CCC Dose (cGy)	MC[a] Dose (cGy)	IC - CCC Diff. (cGy)	IC - CCC Diff. (%)
Center	1.65	1.50	1.50	0.15	9.1	1.75	1.50	1.54	0.25	14.3
12 O'clock	0.26	0.20	0.14	0.06	23.1	3.05	2.90	3.02	0.05	1.6
3 O'clock	2.43	2.40	2.24	0.03	1.2	2.96	3.00	3.01	-0.04	-1.4
6 O'clock	4.42	4.60	4.67	-0.19	-4.3	2.87	3.00	2.93	-0.13	-4.5
9 O'clock	3.86	3.90	4.07	-0.04	-1.0	2.89	2.90	3.01	-0.01	-0.3
$CTDI_w$	2.38	2.35	2.35	0.03	1.3	2.54	2.47	2.51	0.08	3.1

[a] IC and MC data are presented with permission of published journal.[13]
[b] Location refers to that in Fig. 1.
IC = ion chamber; CCC = collapsed cone convolution; MC = Monte Carlo.

Kim S and Alaei P. J App Clin Med Phys 17(2): 153-164



Pawlowski JM and Ding GX. An algorithm for kilovoltage x-ray dose calculations with applications in kV-CBCT scans and 2D planar projected radiographs, PMB 59: 2041-2058 (2014)

Measured Dose vs Monte Carlo Calc

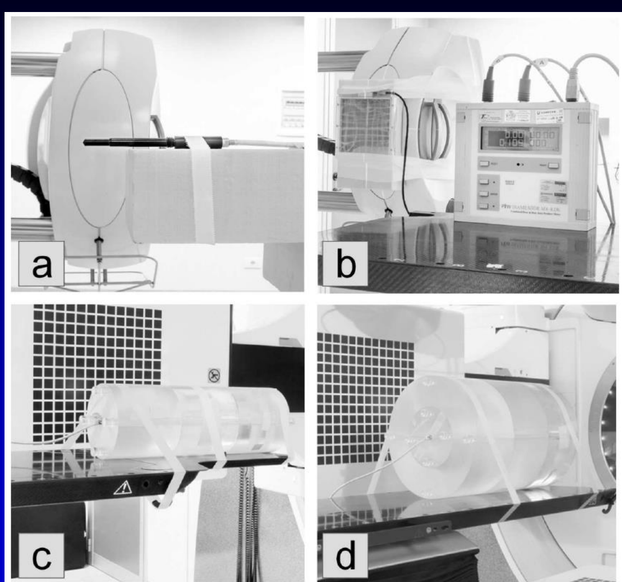
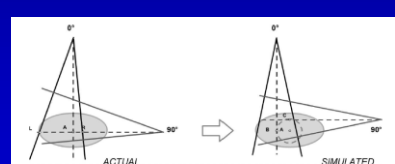
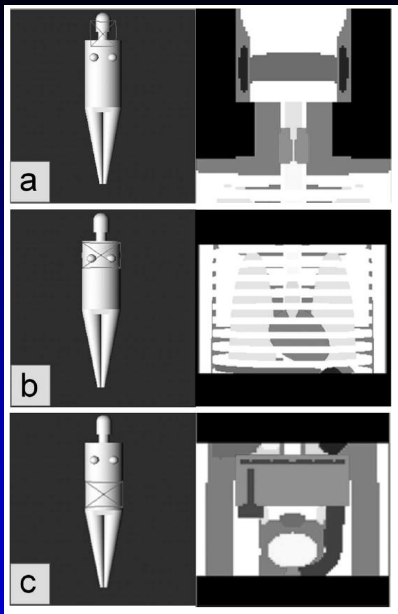


TABLE I. CBCT acquisition parameters for different protocols. The difference between chest F1 and pelvis only rely on the acquired anatomical district.

	Head & neck	Chest 4D (symmetry)	Chest F0	Chest F1	Pelvis
kV	100	100	120	120	120
mA/frame	10	20	25	40	40
ms/frame	10	16	40	40	40
Total mAs	36.6	422.4	660	1056	1056
Collimation	S20	S20	M20	M20	M20
Filter	F0	F0	F0	F1	F1
Rotation	200° (−130° to 70°)	200° (−180° to 20°)	360° (−180° to 180°)	360° (−180° to 180°)	360° (−180° to 180°)
No. frames	366	1320	660	660	660



Rampado et al.: Dose indicators and organ doses in radiotherapy CBCT. Med Phys 43(5): 2515-2526 (2016)



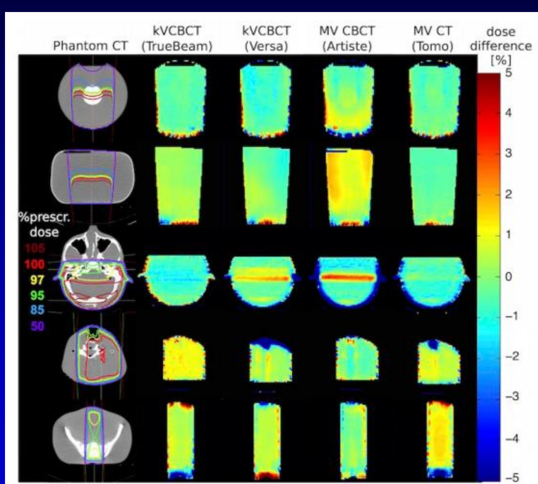
Measured Dose vs Monte Carlo Calc

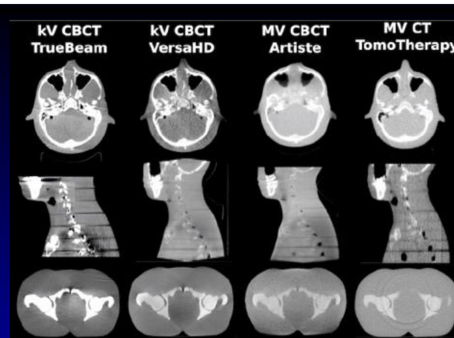
TABLE VII. Comparison of organ doses (mGy) evaluated by TLD measurements in the Rando phantom and with the PCXMC software.

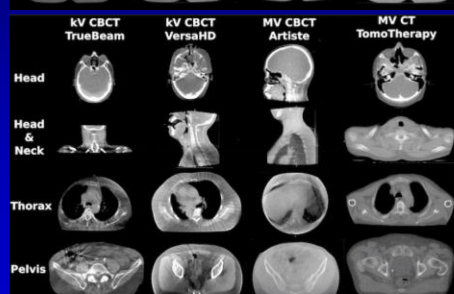
Protocol	Organ	PCXMC	TLD	% diff
Head & neck	Oral mucosa	0.89	0.82	8
	Salivary glands	0.93	0.95	−3
	Respiratory airways	0.84	1.01	−16
Chest 4D (symmetry)	Lungs	8.9	7.9	12
	Heart	10.1	10.2	−1
	Breasts	15.6	16.0	−2
Chest F0	Lungs	21.7	19.9	9
	Heart	20.4	20.2	1
	Breasts	21.3	19.2	11
Chest F1	Lungs	20.9	21.5	−3
	Heart	23.1	23.3	−1
	Breasts	18.6	17.3	8
Pelvis	Ovaries	19.7	22.3	−12
	Colon	16.4	18.2	−10
	Prostate	16.0	13.5	18
	Bladder	22.5	21.5	5

Rampado et al.: Dose indicators and organ doses in radiotherapy CBCT.
Med Phys 43(5): 2515-2526 (2016)

Dose Calculation Accuracy for kV CBCT, MV CBCT and MV CT







Held M, Cremers F, Sneed PK, Braunstein S, Fogh SE, Nakamura J, Barani I, Perez-Andujar A, Pouliot J, Morin O. Assessment of image quality and dose calculation accuracy on kV CBCT, MV CBCT, and MV CT images for urgent palliative radiotherapy treatments. JACMP 17(2): 279-290. (2016)

TABLE 1. Difference in calculated dose for prescription 1 relative to the treatment planning CT.

Phantom	kV CBCT (TrueBeam) γ-index (3%/3mm)	kV CBCT (TrueBeam) Mean (%) SD	kV CBCT (Versa) γ-index (3%/3 mm)	kV CBCT (Versa) Mean (%) SD	MV CBCT (Artiste) γ-index (3%/3 mm)	MV CBCT (Artiste) Mean (%) SD	MV CT (Tomo) γ-index (3%/3 mm)	MV CT (Tomo) Mean (%) SD
Water Cylinder	97.28	-0.28 2.38	97.20	-0.59 2.69	96.74	-0.71 6.46	97.03	-0.44 3.71
Water Pelvis	99.37	0.27 0.80	99.35	-0.05 0.82	99.13	0.21 5.42	100.00	-0.29 0.63
Head	94.36	-1.93 4.28	99.67	-1.15 6.25	96.70	-3.74 12.52	99.47	-1.73 6.08
Neck	99.62	0.64 4.99	97.88	-3.54 15.15	99.51	-0.32 6.78	99.25	-0.96 8.99
Hip	99.99	-0.15 4.74	99.81	0.59 2.37	99.86	-0.22 3.78	99.99	0.18 4.92

TABLE 2. Image dose, noise, CNR, uniformity, and spatial resolution.

	$CTDI_{vol}$ (cGy) rFOV/eFOV	Noise	CNR (bone/water)	Uniformity	Spatial Resolution 50% cf (1/cm)
kV CT (MX 8000)	0.20	0.53	161.5	0.1	4.1
kV CBCT (TrueBeam)	0.29/1.43[a]	2.10	52.2	-1.0	4.1
kV CBCT (Versa)	0.12/2.20[a]	3.07	36.7	6.7	2.1
MV CBCT (Artiste)	5.00/15.00[b]	1.91	14.9	-4.5	1.6
MV CT (Tomo)	~ 2.00[b]	3.14	15.7	0.0	2.1

[a] $CTDI_w$, [b] dose

TABLE 5. Summary of clinically important factors for each on-board imaging system.

	kV CBCT (TrueBeam)	kV CBCT (Versa)	MV CBCT (Artiste)	MV CT (Tomo)
Multiple IVDC calibrations necessary?	no	yes	yes	no
Mean dose calculation accuracy < 5% / < 10% including 1 SD?				
Head	no/yes	no/yes	no/no	no/yes
Neck	no/yes	no/no	no/yes	no/yes
Pelvis	yes/yes	yes/yes	yes/yes	no/yes
Difference of prescribed MU to mid-plane < 5%?	yes	yes	yes	yes
Max. field of view (diameter, length (cm))	45, 15	50, 27	31, 25	40, 26[c]
Acquisition & reconstruction time	< 2 min	< 2 min	< 2 min	~ 5 min[a]

[a] Scan length variable – acquisition time estimated for 26 cm scan length.

Held M, Cremers F, Sneed PK, Braunstein S, Fogh SE, Nakamura J, Barani I, Perez-Andujar A, Pouliot J, Morin O. Assessment of image quality and dose calculation accuracy on kV CBCT, MV CBCT, and MV CT images for urgent palliative radiotherapy treatments. JACMP 17(2): 279-290. (2016)

IGRT Dose Is Centered At the Treatment Isocenter

IGRT Practices Vary Across Institutions

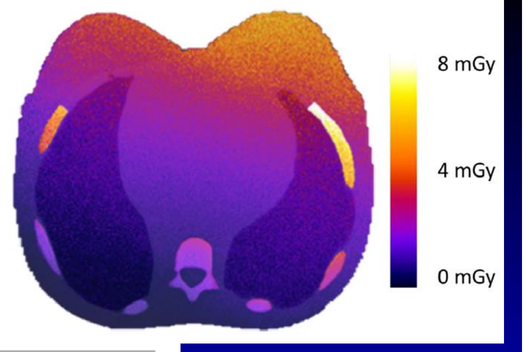


Table 7
Number of images and resulting cumulative organ doses in breast treatments.

	Treatment fractions	kV radiographs AP/PA	kV radiographs LAT	kV radiographs OBL	CBCT's	Cumulative dose (mGy) Contralateral breast	Lung	Contralateral lung	Heart	Sternum (RBM)
UH1	15	–	–	5	–	0.8	1.0	0.1	8.5	1.5
	25	–	–	7	–	1.1	1.4	0.1	12	2.0
	30	–	–	8	–	1.2	1.6	0.2	14	2.3
	15	–	–	–	5	1.0	0.6	0.3	1.0	1.2
	25	–	–	–	7	1.3	0.8	0.4	1.4	1.7
	30	–	–	–	8	1.5	1.0	0.5	1.6	1.9
UH2	15	5	5	5	–	2.1	7.6	1.0	19	5.4
	25	7	7	7	–	2.9	11	1.4	26	7.5
	15 DIBH	5	5	14	–	3.4	9.4	1.2	34	8.0
	25 DIBH	7	7	23	–	5.3	14	1.7	53	12
	15 VMAT	5	5	5	3	17	19	11	34	14
	25 VMAT	7	7	7	5	28	30	17	51	22
UH3	16	3	3	3	–	1.2	4.6	0.6	11	3.2
	26	3	3	3	–	1.2	4.6	0.6	11	3.2
	16 DIBH	3	3	16	–	3.2	7.2	0.9	33	7.0
	26 DIBH	3	3	26	–	4.7	9.2	1.1	50	10
CH1	5	16	5	–	–	1.4	6.8	1.0	11	4.6
	25	25	7	–	–	2.0	9.6	1.4	15	6.6
CH2	15	3	3	–	–	0.8	4.0	0.5	6.1	2.3

Siiskonen T et al. Imaging practices and radiation doses from imaging in radiotherapy. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.03.012

Patient CBCT Dose Measurements

Table 1. Scanning conditions in cone beam computed tomography.

Site of scan	Scanning mode	Filter	kV	mA	ms	Field size
Head and neck	High resolution	Full	100	80	25	13.6 × 9.2 cm^2
Head and neck	Standard	Full	100	20	10	13.6 × 9.2 cm^2
Chest	Standard	Half	110	20	20	26.6 × 20 cm^2
Pelvis	Standard	Half	125	80	13	26.6 × 20 cm^2

To date, there have been many measurements and calculations of imaging doses resulting from CBCT in IGRT (Yi et al. 2011; Ding et al. 2008; Hyer and Hintenlang 2010). Measurements of radiation dose with thermoluminescent dosimeters (TLD) from OBI-based CBCT found that the mean surface doses per scan for the head and neck, chest, and pelvis were 6.7, 6.4, and 5.4 cGy, respectively, whereas the total effective doses were 10.3, 23.7, and 22.7 mSv, respectively (Kan et al. 2008). Use of a Farmer chamber with software Version 1.4 to assess radiation dose from OBI-based CBCT revealed that the weighted Computed Tomography Dose Index ($CTDI_w$) values for scans of the head and neck and pelvis were 36.6 and 29.4 mGy, respectively (Cheng et al. 2011), corresponding to effective doses of 1.7 and 8.2 mSv, respectively. Use of thermoluminescent dosimeters to measure radiation dose from an OBI-based CBCT system resulted in relatively low effective doses of 0.3 and 2.7 mSv for scans of the head and neck and pelvis, respectively (Dufek et al. 2011).

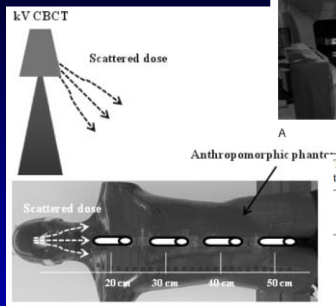


Fig. 2. Schematic picture for measuring secondary doses in an a thropomorphic phantom during CBCT, located 20, 30, 40, and 50 from the beam isocenter.

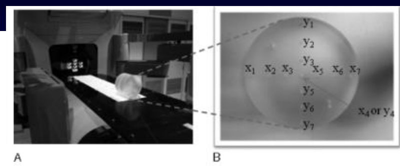


Table 3. Average organ doses per scan from kV cone-beam CT of the head and neck, chest, and pelvis.

	Organ doses per scan (10^{-2} Gy)		
Organ	Head and neck	Chest	Pelvis
Eye	0.59	0.0045	0.024
Thyroid	0.26	0.28	0.026
Lung	0.023	2.6	0.085
Stomach	0.0093	2.0	0.42
Liver	0.0066	0.91	0.29
Colon	0.0033	0.018	8.3
Bladder	0.0029	0.026	9.5
Prostate	0.0022	0.023	8.4

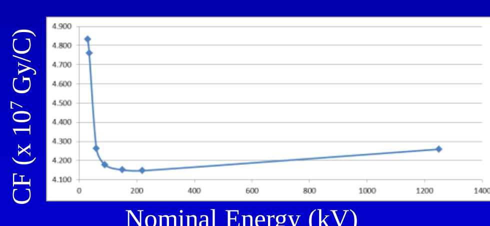
	ERR[a]		EAR[b]		LAR[c]	
Organ	Male	Female	Male	Female	Male	Female
Lung	0.01	0.04	0.06	0.09	3.6	7.7
Stomach	0.03	0.06	0.62	0.62	4.3	5.4
Liver	0.03	0.03	0.19	0.09	2.3	1.0
Colon	1.57	1.07	7.97	3.98	398	239
Bladder	1.43	4.70	3.42	2.14	279	—
Prostate	0.30	—	3.02	—	111	—

Kim DW et al. Imaging doses and secondary cancer risk from kilovoltage cone-beam CT in radiation therapy. Health Physics 104(5): 499-503. (2013)

Patient CBCT Dose Measurements

- Can be challenging
- Dosimeters: TLD, OSLD, Ion Chamber, potentially solid state (must be careful here)
- Dosimeter must be calibrated at kV energy, an MV calibration factor will not work
- Example:

Graphite Farmer ionization chamber calibration factors from 30 kv to 1.25 MeV (Co-60)



kV Fan-Beam CT IGRT Doses

TABLE VII. Mean Values of the effective dose (E), $CTDI_{vol}$, and DLP (Ref. 75).

Examination	Period (yr)	E (min–max) (mSv)	$CTDI_{vol}$ (min–max) (mGy)	DLP (min–max) (mGy cm)
Head	2002	2.2 (1.3–3.7)	79 (45–116)	991 (590–1626)
Chest	2002	5.8 (1.8–11.3)	10 (4–17)	317 (102–647)
Abdomen	2002	11.4 (7.4–14.7)	12 (8–19)	643 (389–847)
LS	2000	4.3 (2.3–9.3)	34 (19–54)	265 (165–396)

Murphy MJ et al. The management of imaging dose during imaged-guided radiotherapy: Report of the AAPM Task Group 75. Med. Phys. 34(10), October 2007.

Orthogonal-Planar IGRT Doses

CyberKnife, ExacTrac

TABLE I. Measured planar radiographic entrance dose levels per image for the CyberKnife image-guided radiosurgery system.

Site	kV	mA	ms	mAs	mGy
Cranium and C-spine	105–125	100	100	10	0.25
T-spine	120–125	100–150	100–125	10–20	0.25–0.50
L-spine	120–125	100–200	100–150	10–30	0.25–0.75
Sacrum	120–125	100–300	100–300	10–90	0.25–2.00
Synchrony	120–125	100–300	50–75	5–22.5	0.10–0.50

Murphy MJ et al. The management of imaging dose during imaged-guided radiotherapy: Report of the AAPM Task Group 75. Med. Phys. 34(10), October 2007.

kV CBCT IGRT Doses

TABLE VIII. Dose from kV cone-beam CT (Ref. 45).

Parameter	Head	Chest
Maximum skin dose (mGy)	100.5	85.4
Mean skin dose (mGy)	68.5	57.0
Effective dose (mSv)	10.9	24.6
Conversion factor (mSv/mGy cm^2)	6.0×10^{-5}	16.0×10^{-5}

Murphy MJ et al. The management of imaging dose during imaged-guided radiotherapy: Report of the AAPM Task Group 75. Med. Phys. 34(10), October 2007.

kV CBCT IGRT Doses

TABLE IX. Dose from the Elekta XVI kV cone-beam CT (Ref. 42).

Parameter	Head	Chest
Mean dose at center (mGy)	29	16
Mean skin dose (mGy)	30	23
Effective dose (mSv)	3.0	8.1
Conversion factor (mSv/mGy cm^2)	6.0×10^{-5}	16.0×10^{-5}

Murphy MJ et al. The management of imaging dose during imaged-guided radiotherapy: Report of the AAPM Task Group 75. Med. Phys. 34(10), October 2007.

MV CBCT IGRT Doses

Anatomical Site	Artiste	Oncor/Primus
Head and Neck	3.4 cGy	4.5 cGy
Thorax	5 cGy	7 cGy
Pelvis	5 cGy	7 cGy

Morin and Pouliet, Chapter 6, MV CBCT in IGRT, in Image-Guided Radiation Therapy (ed, Bourland)

6 MV Portal Image Doses (E)

TABLE X. Effective dose E from 6 MV portal images 18 cm $\times$ 15.6 cm taken at SSD=88 cm (Ref. 68).

Port View	Gender	Effective Dose E (mSv/MU)
AP pelvis	Male	0.34
	Female	0.52
Lat pelvis	Male	0.32
	Female	0.7
AP chest	Male	1.74
	Female	1.8
Lat chest	Male	2.56
	Female	2.23
Lat neck	N.A.	0.12

Murphy MJ et al. The management of imaging dose during imaged-guided radiotherapy: Report of the AAPM Task Group 75. Med. Phys. 34(10), October 2007.

IV.C. Image dose

CT-based IGRT has progressed rapidly as experience has shown it to be a good means for identifying and correcting geometric errors prior to initiating radiation therapy. Daily imaging doses are generally small compared to therapeutic doses but are distributed over the entire imaged volume. Dosimetric CT-based imaging studies have been published[10,22,24,172,176,177] and report dose ranging from 0.1 to 2 cGy/scan for kV-CBCT and 0.7 to 10.8 cGy/scan for MV-CBCT. For fan-beam MVCT images, the doses range from 0.7 to 4 cGy and depend on the selected CT pitch and the imaged anatomy thickness.[24] Dose can, therefore, cumulate from 3 to 370 cGy over a course of treatment, above the threshold doses reported in the literature for secondary malignancy occurrence.[178,179]

Bissonnette et al., Quality assurance for image-guided radiation therapy utilizing CT-based technologies: A report of the AAPM TG-179. Med. Phys. 39 (4), April 2012.

CBCT Dose Summary

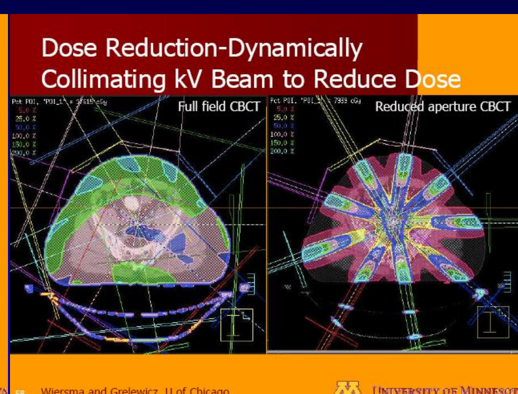
IGRT Technique	Dose (cGy)	% 2 Gy/fx
• MV CBCT: Siemens Mvision	5-17	2.5-8.5
• kV CBCT: Varian OBI	1-8	0.5-4.0
– Low dose mode less by 1/5		
• kV CBCT: Elekta XVI	0.1-3.5	0.05-1.8
– Bowtie mode less by 1/4 to 1/5		
• kV Conventional CT (body/head)	1 / 5	NA
• kV Fluoroscopy (orthogonal)	~ 5 cGy/min	(skin dose)

Alaei P. Review of the Doses from Cone Beam CT and Their Inclusion in the Treatment Planning https://www.medicaldosimetry.org/pub/39774274-2354-d714-51f0-8be87ec1b43b

IGRT Dose Reduction

- “Low dose modes” – depend on image receptor sensitivity, acquisition modes, and anatomy being imaged – like diagnostic imaging techniques
- Pulsed fluoroscopy, adjustable FOV collimation, limited FOV reconstruction algorithms (“interior reconstruction” for CT)
- Adjustable output for MV CBCT + EPID (similar to auto beam current adjustment for CT imaging)

Dynamic Collimation, Interior Reconstruction



Alaei P. Review of the Doses from Cone Beam CT and Their Inclusion in the Treatment Planning https://www.medicaldosimetry.org/pub/39774274-2354-d714-51f0-8be87ec1b43b

IGRT Dose Avoidance

- Choose procedure and frequency of imaging that best matches the need: daily or weekly imaging?
- Choose FOV and "minimum" technique factors matched to minimum required image quality for the anatomical site – specify protocols for each site
  - Imaging FOV is always larger than treatment fields – treatment field scatter has largest lateral path length
- Special attention to pediatric patients, implanted devices – D < 200 cGy typical maximum dose for implanted devices

Ding G, X-ray Imaging Dose to Therapy Patients, http://www.aapm.org/meetings/amos2/pdf/60-14838-42385-312.pdf

IGRT Dose Records

- Most important for MV CT approaches (FBCT, CBCT)
- For kV CBCT, could calculate IGRT dose distribution and sum to MV radiation treatment plan (cumulative dose)
  - Computation models still in development, so computing and summation difficult – a useful step?
- Calculate and record specific organ or device doses
- Add a certain dose for each IGRT procedure to the patient's dose record, eg, "2 cGy" or some other dose number – is this relevant to prescription point?
- Most common kV CBCT approach: with ~1% dose, record imaging procedure, but <u>do not</u> record the imaging dose

Summary

- IGRT dose distributions are "omni-directional," compared to MV radiation treatment dose distributions
- Fortunately, kV IGRT doses relatively low, ~ 1% of daily fractional dose – there can be exceptions
- MV IGRT doses can be higher per fraction, 4-7%
- Dose to skin, other organs could exceed deterministic limits for radiation-induced morbidity (MV, fluoroscopy)

Summary

- Dose calculations and CTDI measurements (eg, TG 111 approach) can be challenging to implement
- Individual patient in vivo dosimetry is needed
- Special cases deserve attention: pediatric, implanted devices, perhaps superficial (skin), larger FOV applications
- Low dose kV modes in development

- Thus, characterize IGRT device, decide on dose recording, decide on "recorded dose" due to imaging