Imaging doses in radiation therapy from kilovoltage cone-beam computed tomography

May 3, 2011

Dan Hyer, PhD

Overview

- Introduction to kV-CBCT
- Present imaging doses from both the Elekta XVI and Varian OBI kV-CBCT systems
- Image quality comparison
- Introduce and discuss a new metric
  - Cone-beam dose index
- Techniques for estimating imaging doses from kV-CBCT

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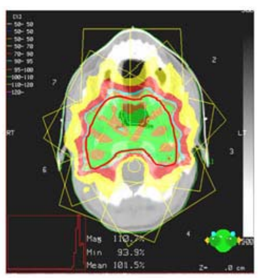
Introduction to CBCT imaging

- Advances in radiation therapy that allow conformal treatments
- Patient must be accurately positioned during each treatment session



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Verifying patient positioning

- Traditional method for position verification
  - Pair of orthogonal MV radiographs are compared to Digitally Reconstructed Radiographs (DRRs) from the planning CT
    - 4-16 cGy per image pair
- kV-CBCT
  - Use gantry mounted kV x-ray unit and flat panel detector to create a volumetric image (CBCT) which can be registered with the planning CT
    - 1-10 cGy

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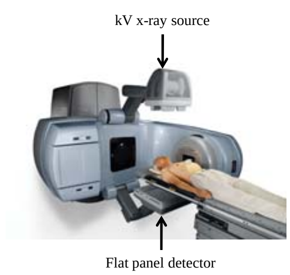
kV-CBCT components

- Technology is currently offered by two major medical linac manufacturers
  - Varian On-Board Imager (OBI)
  - Elekta X-ray Volumetric Imager (XVI)



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Advantages of kV-CBCT

- Advantages of kV-CBCT compared to MV radiographs
  - Lower radiation dose
  - Can identify soft-tissue targets
    - Superior image quality
      - 3D versus 2D images
      - kV inherently better contrast than MV imaging

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Disadvantages of kV-CBCT

- Disadvantages of kV-CBCT compared to MV radiographs
  - Imaging dose is not taken into account in the treatment planning process*
    - Daily imaging, 30 treatment fractions
      - Dose can exceed 1 Gy
    - Problem magnified by the fact that many organs near the treatment volume approach dose limits from the treatment beam alone
  - Solution: Identify imaging doses!

*P. Alaei, G. Ding and H. Guan, "Inclusion of the dose from kilovoltage cone beam CT in the radiation therapy treatment plans," Med Phys 37, 244-248 (2010)

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How do we quantify organ doses?

- Monte Carlo simulations
  - Simulate kV-CBCT along with a virtual human phantom
  - Uncertainties
    - Photon spectrum, geometry of irradiation, etc
- Physical measurements
  - Perform organ dose measurements in a physical anthropomorphic phantom
  - Requires specialized equipment
    - Eliminates uncertainties of Monte Carlo simulations

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Previous CBCT anthropomorphic phantom studies

The British Journal of Radiology, 80 (2007), 476–482

Imaging doses from the Elekta Synergy X-ray cone beam CT system

[1]A AMER, PhD, [1]T MARCHANT, PhD, [2]J SYKES, MSc, [1]J CZAJKA, MSc and [1]C MOORE, PhD

[1]North Western Medical Physics, Christie Hospital NHS Trust, Manchester M20 4BX and [2]Cookridge Hospital, Hospital Lane, Leeds LS16 6QB, UK

- Rando phantom with TLDs
- Limited organs investigated
- Utilized protocols that were developed prior to the introduction of bow-tie filters

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Previous CBCT anthropomorphic phantom studies

IOP Publishing — Physics in Medicine and Biology

Phys. Med. Biol. 52 (2007) 2267–2276

Dose delivered from Varian's CBCT to patients receiving IMRT for prostate cancer

Ning Wen, Huaiqun Guan[1], Rabih Hammoud, Deepak Pradhan, T Nurushev, Shidong Li and Benjamin Movsas

Henry Ford Health System, Detroit, MI, USA

Received 17 August 2006, in final form 11 December 2006
Published 2 April 2007
Online at stacks.iop.org/PMB/52/2267

- Rando phantom along with TLDs
- Varian OBI system
  - Limited data, only investigated pelvis protocol

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Previous CBCT anthropomorphic phantom studies

ELSEVIER

doi:10.1016/j.ijrobp.2007.08.062

PHYSICS CONTRIBUTION

RADIATION DOSE FROM CONE BEAM COMPUTED TOMOGRAPHY FOR IMAGE-GUIDED RADIATION THERAPY

Monica W. K. Kan, M.Phil., Lucullus H. T. Leung, Ph.D., Wicger Wong, M.Sc., and Nelson Lam, M.Phil.

Department of Oncology, Princess Margaret Hospital, Hong Kong SAR, China

- RANDO anthropomorphic phantom and TLDs
- Varian OBI system
  - Investigated head, chest, and pelvis protocols
  - Protocols since this study have been significantly updated
    - Previously fixed at 125 kVp and full rotation scans

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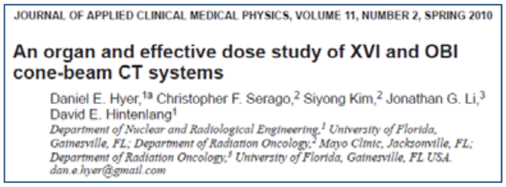
And our study…


JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 11, NUMBER 2, SPRING 2010

An organ and effective dose study of XVI and OBI cone-beam CT systems

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- Both Varian OBI and Elekta XVI
- Factory installed protocols: head, chest, pelvis

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Phantom

- Measured using an in-house 50th percentile adult male anthropomorphic phantom
  - Soft tissue, bone tissue, lung tissue

J.F. Winslow, **D.E. Hyer**, R.F. Fisher, C.J. Tien and D.E. Hintenlang, "Construction of anthropomorphic phantoms for use in dosimetry studies," J Appl Clin Med Phys 10, 195-204 (2009)

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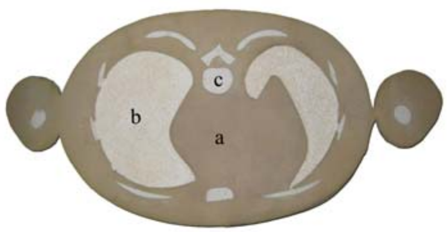
Phantom slice



- Completed axial slice with (a) STES, (b) LTES, and (c) BTES
- ~200 slices (5mm thick) for entire phantom

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Dosimetry system

- In-house fiber-optic coupled dosimetry system
- ~4% uncertainty

D.E. Hyer, R.F. Fisher and D.E. Hintenlang, "Characterization of a water-equivalent fiber-optic coupled dosimeter for use in diagnostic radiology," Med Phys 36, 1711-1716 (2009)

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Other dosimeters available

- TLD or OSLs
  - Post-irradiation readout can be time consuming
  - Inexpensive and widely available
- MOSFETs or Diodes
  - Real-time readout
  - Energy and angular dependence issues

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FOC dosimeter installed in slice

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Clinical protocols

	XVI			OBI		
Scan site	Head	Chest	Pelvis	Head	Chest	Pelvis
kV collimator	S20	M20	M10	-	-	
kV filter	F0	F1	F1	Full bowtie	Half bowtie	Half bowtie
kVp	100	120	120	100	110	125
mA	10	40	64	20	20	80
ms/projection	10	40	40	20	20	13
# of projections	361	643	643	360	655	655
Total mAs	36.1	1028.8	1646.1	145	262	680
Meaured HVL (mm Al)	5.9	8.9	8.9	5.4	5.7	6.4
Acquisition angle	350°-190° cw	273°-269° cw	273°-269° cw	88°-292° cw/ccw	88°-92° cw/ccw	88°-92° cw/ccw
Acquisition time	~70 s	~120 s	~120 s	~30 s	~60 s	~60 s
Axial field of view (cm)	27	41	41	25	45	45
Long. field of view (cm)	26	26	12.5	18	16	16

*Software version 4.0 for XVI and software version 1.4.13.0 for OBI

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Head protocols for both kV-CBCT systems utilized

0% 1. partial rotation scans

0% 2. an accelerating voltage of 175 kV

0% 3. non-isocentric rotation

0% 4. a carbon filter

0% 5. full rotation scans

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Answer

- 1. Partial rotation scans
  - Both systems use ~180° rotation for head protocols

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Organs investigated

- Taken from ICRP 103 recommendations for the calculation of effective dose

Tissue	w_T
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12
Gonads	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04
Bone surface, Brain, Salivary glands, Skin	0.01

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (male), Small intestine, Spleen, Thymus

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Measurement points in each organ

- Small organs
  - Single dose measurement near centroid of organ
- Large organs
  - Organs were equally subdivided and dosimeters were placed near the centroid of each of these subdivisions
  - Average reading from all dosimeters placed in the organ was adopted as organ dose

Tissue/organ	Measurement points
Brain	4
Salivary glands	6
Thyroid	1
Esophagus	6
Lung	8
Breast	2
Liver	4
Stomach	4
Colon	10
Bladder	1
Gonads (testes)	2
Bone marrow	19
Bone surface	19
Skin	2
Remainder organs	
Extrathoracic region	4
Oral mucosa	1
Thymus	1
Heart	1
Spleen	2
Adrenals	2
Gall bladder	1
Kidneys	2
Pancreas	1
Small intestine	6
Prostate	1
Other organs	
Lens	2

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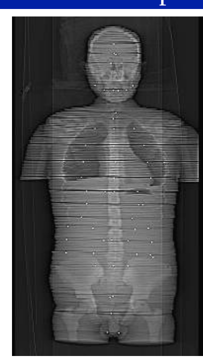
Measurement points



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Dose to red bone marrow and bone surface

$$D_{\text{RBM}} = \sum_i D_{\text{abs},i} * A_i$$

$$D_{\text{BS}} = \sum_i D_{\text{abs},i} * E_i$$

A_i = weight fraction of RBM at bone site i

E_i = weight fraction of endosteum (BS) at bone site i

	A_i	E_i
Cranium	0.049	0.118
Cervical vertebrae	0.032	0.021
Humerus-proximal	0.031	0.027
Clavicles	0.011	0.007
Scapula	0.091	0.070
Ribs	0.102	0.042
Sternum	0.026	0.010
Thoracic vertebrae	0.130	0.048
Lumbar vertebrae	0.130	0.054
Os coxae	0.265	0.173
Sacrum	0.081	0.037
Femur-proximal	0.045	0.065
Sum	0.991	0.672

*Lee C, Lodwick D, Hurtado J, Pafundi D, Bolch WE. Development of a series of hybrid computational phantoms and their applications to assessment of photon and electron specific absorbed fractions. 2008 Annual Meeting of the European Association of Nuclear Medicine, Munich, Germany.

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Dose to lung tissue

$$D_{\text{lung}} = D_{\text{abs}} \left[\left(\frac{\overline{\mu}_{\text{en}}}{\rho} \right)^{\text{lung}}_{\text{soft tissue}} \right]$$

$\left(\frac{\overline{\mu}_{\text{en}}}{\rho} \right)^{\text{lung}}_{\text{soft tissue}}$ = Ratio of mass energy absorption coefficients of lung tissue to soft tissue at the measured HVL, taken from TG61

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Dose to skin

$$D_{\text{skin}} = D_{\text{abs}} * \frac{A_{\text{irradiated}}}{A_{\text{total}}} * \left[\left(\frac{\overline{\mu}_{\text{en}}}{\rho} \right)^{\text{skin}}_{\text{soft tissue}} \right]$$

- Computational model used to estimate skin area
  - Total skin area = 1.83 m^2
  - Head scan = 0.12 m^2
  - Chest scan = 0.32 m^2
  - Pelvis scan = 0.20 m^2

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Extrathoracic and salivary glands

- Extrathoracic
  - Average dose to nasal layer (posterior and anterior), pharnyx, and larnyx
- Salivary glands
  - Average dose to parotid, submaxillary, and sublingual gland

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Effective dose

$$E = \sum_{\text{T}} w_{\text{T}} H_{\text{T}}$$

- “Reference male” effective dose
  - No measurements done in female phantom
  - Simply for comparison between different protocols
  - Remember, the dose to two remainder organs was not measured (lymphatic nodes and muscle)
    - The dose to all other remainder organs was averaged and w_{T} was applied to this value

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Positioning of phantom on treatment table

- Typical clinical isocenters were chosen
  - Head
    - Center of brain
  - Chest
    - Center of the body at an axial plane near the center of the lungs
  - Pelvis
    - Center of the prostate

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Holding it all together

- Phantom was held together on the table during imaging with a patient immobilization vacuum bag

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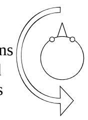
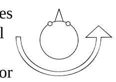
- Head scan
  - XVI
    - 36.1 mAs
    - Image acquisition begins anterior, rotates around left lateral, and finishes posterior
      - Many superficial organs on anterior side of head
  - OBI
    - 145 mAs
    - Image acquisition moves from left to right lateral (or vice-versa) while rotating around posterior side of head





Tissue/organ	Organ doses (mGy) XVI	OBI
Brain	0.70	3.01
Salivary glands	0.78	2.42
Thyroid	0.05	0.00
Esophagus	0.02	0.01
Lung	0.01	-
Breast	-	-
Liver	-	-
Stomach	-	-
Colon	-	-
Bladder	-	-
Gonads (testes)	-	-
Bone marrow (whole body)	0.07	0.28
Bone marrow (irradiated site)	0.80	3.45
Bone surface (whole body)	0.11	0.47
Bone surface (irradiated site)	0.80	3.45
Skin (whole body)	0.09	0.16
Skin (irradiated site)	1.34	2.39
Remainder organs		
Extrathoracic region	0.60	1.06
Oral mucosa	0.69	1.39
Thymus	0.01	-
Heart	-	-
Spleen	-	-
Adrenals	-	-
Gall bladder	-	-
Kidneys	-	-
Pancreas	-	-
Small intestine	-	-
Prostate	-	-
Other organs		
Lens	1.07	0.59
Effective dose (msV)	0.04	0.12

- Chest scan
  - XVI
    - 1028.8 mAs
    - 26 cm beam width
      - Irradiates organs far outside of treatment volume (thyroid)
    - HVL = 8.9 mm Al
  - OBI
    - 262 mAs
    - 16 cm beam width
    - HVL = 5.7 mm Al

Tissue/organ	Organ doses (mGy) XVI	OBI
Brain	0.49	0.14
Salivary glands	1.86	0.30
Thyroid	19.24	2.38
Esophagus	13.56	3.23
Lung	14.29	4.31
Breast	16.80	5.34
Liver	6.58	0.97
Stomach	4.68	0.74
Colon	0.40	-
Bladder	0.03	-
Gonads (testes)	-	-
Bone marrow (whole body)	5.14	1.29
Bone marrow (irradiated site)	12.42	3.27
Bone surface (whole body)	2.59	0.63
Bone surface (irradiated site)	12.42	3.27
Skin (whole body)	2.62	1.03
Skin (irradiated site)	14.92	5.85
Remainder organs		
Extrathoracic region	5.21	0.85
Oral mucosa	1.34	0.38
Thymus	14.29	4.83
Heart	13.87	4.50
Spleen	7.17	0.93
Adrenals	3.76	0.65
Gall bladder	1.83	0.14
Kidneys	1.20	0.08
Pancreas	1.21	0.06
Small intestine	0.28	-
Prostate	-	-
Other organs		
Lens	0.52	0.15
Effective dose (msV)	7.15	1.82

- Pelvis scan
  - XVI
    - 1646.1 mAs
    - 12.5 cm beam width
    - HVL = 8.9 mm Al
  - OBI
    - 680 mAs
    - 16 cm beam width
      - More scatter
    - HVL = 6.4 mm Al
      - Lower HVL, higher dose per unit mAs

Tissue/organ	Organ doses (mGy) XVI	OBI
Brain	-	-
Salivary glands	-	-
Thyroid	-	-
Esophagus	-	-
Lung	0.02	0.01
Breast	-	-
Liver	0.19	0.28
Stomach	0.23	0.30
Colon	2.04	3.26
Bladder	15.67	15.30
Gonads (testes)	29.00	34.61
Bone marrow (whole body)	1.05	1.14
Bone marrow (irradiated site)	5.50	5.77
Bone surface (whole body)	1.17	1.14
Bone surface (irradiated site)	5.50	5.77
Skin (whole body)	3.07	3.05
Skin (irradiated site)	27.88	27.77
Remainder organs		
Extrathoracic region	-	-
Oral mucosa	-	-
Thymus	-	-
Heart	0.10	0.08
Spleen	0.20	0.28
Adrenals	0.23	0.34
Gall bladder	0.28	0.52
Kidneys	0.31	0.59
Pancreas	0.33	0.52
Small intestine	1.06	1.72
Prostate	27.63	27.25
Other organs		
Lens	-	-
Effective dose (msV)	3.73	4.34

What about after 30 fractions

- Doses to some organs ~ 1 Gy
  - Testes
    - XVI: 0.87 Gy
    - OBI: 1.04 Gy
  - Prostate
    - XVI: 0.83 Gy
    - OBI: 0.81 Gy
  - Thyroid
    - XVI: 0.57 Gy

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Per fraction, the dose to organs in the primary beam from kV-CBCT imaging is approximately:

0%	1. < 10 cGy
0%	2. 10-20 cGy
0%	3. 20-50 cGy
0%	4. 50-100 cGy
0%	5. > 100 cGy

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Answer

- 1. < 10 cGy
  - All of the organ doses listed in the previous tables are less than 10 cGy, most are less than 3 cGy

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Image quality

- Evaluated basic image quality metrics
  - Spatial resolution
  - Low contrast detectability
- Catphan 440 image quality phantom scanned using clinical protocols
  - Images reconstructed with 5 mm slice width and matrix size of 512x512

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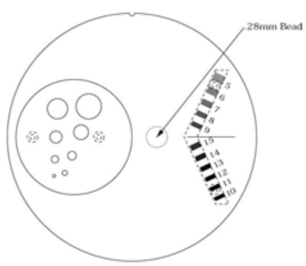
Spatial resolution

- Evaluated using CTP592 module
  - Series of high resolution test patterns from 5 through 15 lp/cm
- Low contrast targets also included
  - Too demanding for CBCT imaging



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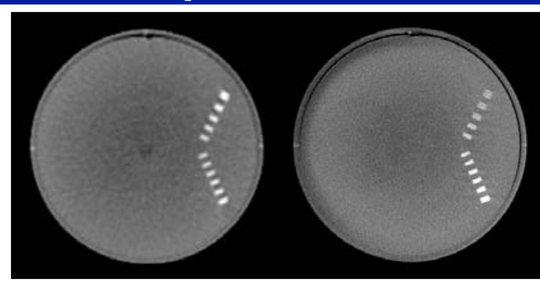
Spatial resolution



XVI OBI

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Low contrast detectability

- Evaluated using CTP401 module
  - Five acrylic spheres of 2, 4, 6, 8, and 10 mm diameter
  - Approximately 3% contrast
  - Evaluated smallest sphere that was visible

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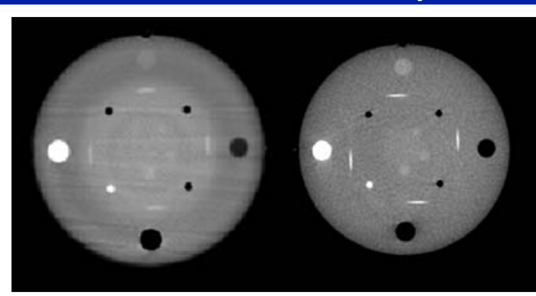
Low contrast detectability



XVI OBI

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Summary of image quality tests

	Head		Chest		Pelvis	
	XVI	OBI	XVI	OBI	XVI	OBI
Resolution	> 5 lp/cm	8 lp/cm	> 5 lp/cm	5 lp/cm	> 5 lp/cm	5 lp/cm
Detectability	> 10 mm	10 mm	6 mm	4 mm	6 mm	4 mm

- OBI exhibited superior image quality using clinical protocols
- Remember, OBI also yielded higher doses for both the head and pelvis scans

Estimate organ doses

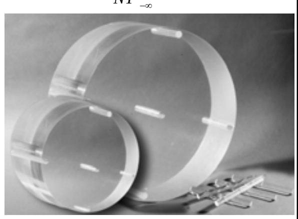
- Goal: Relate organ doses to an easily measured CBCT dose metric
  - Accomplished with the introduction of two quantities
    - Cone beam dose index (CBDI) – Amer *et al.*[1]
    - Organ dose conversion coefficients (ODCCs)

[1]A. Amer, T. Marchant, J. Sykes, J. Czajka, and C. Moore, "Imaging doses from the Elekta Synergy x-ray cone beam CT system," Br. J. Radiol. **80,** 476–482 2007.

Review - CTDI

- CTDI represents the average absorbed dose, along the longitudinal axis, from a series of contiguous irradiations.
- Measured from one axial CT scan (one rotation of the x-ray tube)

$$\mathrm{CTDI} = \frac{1}{NT}\int_{-\infty}^{\infty} D(z)\,dz$$



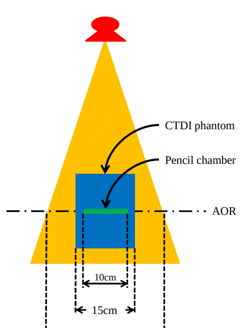
$$\mathrm{CTDI}_{100} = \frac{1}{NT}\int_{-50\mathrm{mm}}^{50\mathrm{mm}} D(z)\,dz$$

Adapting CTDI to CBCT

- Why?
  - Equipment widely available
- Some differences
  - CBCT does not have contiguous slices
  - Longitudinal beam width can be up to 26 cm
- So what are we measuring?

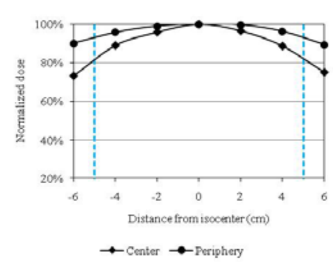
Measuring CBDI

- 100 mm pencil chamber measures average dose over central 100 mm of the longitudinal FOV
  - Due to large beam width, longitudinal dose profile is relatively flat
  - Quantity referred to as CBDI_{100}



Longitudinal dose profile

- XVI chest protocol
  - Center
    - Average = 93.25% of maximum
  - Periphery
    - Average = 97.74% of maximum
- Dose profile is indeed fairly flat, use of pencil chamber slightly underestimates max dose



Measured CBDI values (mGy)

	XVI			OBI		
	Head	Chest	Pelvis	Head	Chest	Pelvis
$CBDI_{100}^{center}$	0.84 ± 0.01	11.34 ± 0.04	16.38 ± 0.04	4.67 ± 0.05	3.65 ± 0.10	13.43 ± 0.13
$CBDI_{100}^{periphery}$	1.05 ± 0.01	19.26 ± 0.06	28.01 ± 0.12	4.57 ± 0.04	6.88 ± 0.02	23.70 ± 0.19
Edge (0°)	1.05 ± 0.02	19.45 ± 0.00	28.85 ± 0.13	1.50 ± 0.04	7.06 ± 0.05	24.18 ± 0.57
Edge (90°)	1.60 ± 0.01	19.01 ± 0.19	28.18 ± 0.22	4.33 ± 0.03	6.83 ± 0.01	23.83 ± 0.09
Edge (180°)	1.10 ± 0.02	18.50 ± 0.11	26.67 ± 0.04	7.16 ± 0.13	6.68 ± 0.02	22.63 ± 0.40
Edge (270°)	0.47 ± 0.01	20.08 ± 0.13	28.32 ± 0.40	5.30 ± 0.04	6.94 ± 0.02	24.18 ± 0.32
$CBDI_{100}^{w}$	0.98 ± 0.01	16.62 ± 0.05	24.13 ± 0.08	4.60 ± 0.03	5.80 ± 0.03	20.28 ± 0.14

$$CBDI_{100}^{w} = \left(\frac{1}{3}\right) CBDI_{100}^{center} + \left(\frac{2}{3}\right) CBDI_{100}^{periphery}$$

↳ Represents average dose in CTDI phantom

How do we relate CBDI to organ doses?

- ImPACT calculator
  - Developed by ImPACT group in UK
  - Matches Monte Carlo data from a mathematical human phantom to measured CTDI values to estimate organ doses
    - Amer *et al.*[1] and Sawyer *et al.*[2] have used the ImPACT calculator along with CBDI values to estimate organ doses from CBCT

[1] A. Amer, T. Marchant, J. Sykes, J. Czajka, and C. Moore, "Imaging doses from the Elekta Synergy x-ray cone beam CT system," Br. J. Radiol. **80,** 476–482 (2007).
[2] L. J. Sawyer, S. A. Whittle, E. S. Matthews, H. C. Starritt, and T. P. Jupp, "Estimation of organ and effective doses resulting from cone beam CT imaging for radiotherapy treatment planning," Br. J. Radiol. **82,** 577–584 (2009).

Using the ImPACT calculator

- CBCT scanners were not modeled by the ImPACT group
  - Must calculate an ImPACT factor and match to an existing scanners in the ImPACT database

$$\text{ImPACT factor} = a * \frac{CBDI_{100}^{center}}{CBDI_{100}^{air}} + b * \frac{CBDI_{100}^{periphery}}{CBDI_{100}^{air}} + c$$

↳ Matching parameter provides a linear correlation between measured scanner data and effective dose

ImPACT factor

	XVI			OBI		
Empirical factors	Head	Chest	Pelvis	Head	Chest	Pelvis
a	0.4738	3.5842		0.4738	3.5842	
b	0.8045	0.6328		0.8045	0.6328	
c	0.0752	-0.0902		0.0752	-0.0902	
$CBDI_{100}^{center}$ [mGy_{air} /100mAs]	2.34	1.10	1.00	3.22	1.39	1.98
$CBDI_{100}^{periphery}$ [mGy_{air} /100mAs]	2.92	1.87	1.70	3.15	2.63	3.49
$CBDI_{100}^{air}$ [mGy_{air} /100mAs]	3.42	4.27	4.31	6.62	8.09	10.58
$CBDI_{100}^{w}$ [mGy_{air} /100mAs]	2.73	1.62	1.47	3.17	2.22	2.98
ImPACT factor	1.09	1.11	0.99	0.69	0.73	0.79

- If ImPACT factor does not match exactly with one in the database, interpolate between two scanners with the closest ImPACT factor

Measured organ doses vs. ImPACT predicted

	XVI			OBI		
	Hyer *et al.*	ImPACT	% difference	Hyer *et al.*	ImPACT	% difference
Head scan						
Brain	0.70	0.77	10.5%	3.01	3.36	11.8%
Lens	1.07	0.80	-25.6%	0.59	2.94	398.4%
Extrathoracic region	0.60	0.05	-91.2%	1.06	0.07	-93.6%
Oral mucosa	0.69	0.77	12.1%	1.39	3.36	142.1%
Salivary glands	0.78	0.77	-0.9%	2.42	3.36	39.0%
Chest scan						
Lung	14.29	19.30	35.1%	4.31	5.80	34.5%
Thymus	14.29	28.65	100.5%	4.83	10.12	109.6%
Heart	13.87	14.65	5.6%	4.50	4.87	8.3%
Breast	16.80	21.30	26.8%	5.34	5.85	9.5%
Pelvis scan						
Bladder	15.67	19.56	24.8%	15.30	20.28	32.5%
Prostate	27.63	19.56	-29.2%	27.25	20.28	-25.6%
Gonads	29.00	21.56	-25.7%	34.61	19.28	-44.3%

*Version 1.0.2 of ImPACT calculator

ImPACT calculator conclusions

- Not suitable for kV-CBCT organ dose estimation
  - CBCT scanners not modeled
  - Does not account for partial rotation scans

So how can we estimate organ doses?

- Introduction of organ dose conversion coefficients (ODCCs)

$$\text{ODCC} = \frac{\text{Organ dose }(\text{mGy})_{\text{tissue}}}{\text{CBDI}_{100}^{w}(\text{mGy})_{\text{air}}}$$

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Why use $CBDI_w$ for ODCCs?

- Easy to measure
- Provides a single number that represents average dose in CTDI phantom
- Simpler to implement than approaches involving a weighting of separate peripheral and central CBDI measurements

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Organ dose conversion coefficients

$$\text{ODCC} = \frac{\text{Organ dose }(\text{mGy})_{\text{tissue}}}{\text{CBDI}_{100}^{w}(\text{mGy})_{\text{air}}}$$

- Most ODCCs near unity
- Deep organs have a lower ODCC than peripheral organs due to changes in dose with depth
- Head scan does not follow these generalizations

	XVI	OBI
Head scan		
Brain	0.71	0.65
Lens	1.09	0.13
Extrathoracic region	0.61	0.23
Oral mucosa	0.70	0.30
Salivary glands	0.79	0.53
Chest scan		
Lung	0.86	0.74
Thymus	0.86	0.83
Heart	0.83	0.78
Breast	1.01	0.92
Pelvis scan		
Bladder	0.65	0.75
Prostate	1.14	1.34
Gonads	1.20	1.71

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Limitations of ODCC

- Developed using current factory installed protocols
  - Changes that could affect validity of ODCC
    - Tube voltage or acquisition angles
  - Changes that should not affect validity of ODCC
    - mA, ms/projection, total number of projections
    - Expected to scale linearly

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Changes to which of the following parameters would have the largest impact on the validity of organ dose conversion coefficients:

0% 1. mA
0% 2. Image reconstruction algorithm
0% 3. Dose rate
0% 4. Accelerating voltage
0% 5. Total number of projections

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Answer

- 4. Accelerating voltage
  - Changing the accelerating voltage would alter the dose distribution in the phantom.

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Conclusions

- Organ doses from kV-CBCT systems are typically <3 cGy/fraction
- With daily imaging, doses can approach 1 Gy
- Must be considerate of imaging doses when creating treatment plans

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  - **D.E. Hyer** and D.E. Hintenlang, “Estimation of organ doses from kilovoltage cone-beam CT imaging used during radiotherapy patient position verification,” Med Phys 37, 4620-4626 (2010)

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