Cone Beam CT: Dose Measurement, Calculation, and Inclusion in the Treatment Plan

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Introduction

- Measurement and calculation of the dose from imaging beams have gained interest following development of cone beam CT systems
- Various dosimeters and algorithms have been used to measure and calculate the imaging dose in phantom and patient
- There have been proposals on the methodology and quantities suitable to describe the dose from CBCT and to quantify the dose to patient

Learning Objectives (1)

- Understand the dosimetric tools and methods used to measure dose from CBCT imaging;
- Understand the methods used to calculate dose from CBCT imaging;
- Understand the methodology used to describe the dose from CBCT imaging;

Learning Objectives (2)

- Understand the methods used to generate beam data from imaging systems for commissioning imaging beams in the treatment planning systems;
- Update on the progress made on the inclusion of the CBCT imaging dose in patient treatment plans using existing commercial planning systems as well as development of new algorithms

Dosimeters and methods

- Megavoltage imaging: Same dosimeters and protocols used for megavoltage dosimetry and beam data acquisition
- Kilovoltage imaging: Same dosimeters (ionization chambers, TLDs, etc.) could be used providing appropriate calibration factors have been obtained and proper calibration protocol is used (i.e. TG 61)
  - Ding and Coffey, "Beam characteristics and radiation output of a kilovoltage cone-beam CT", *Phys. Med Biol.*: 5231-5248 (2010)

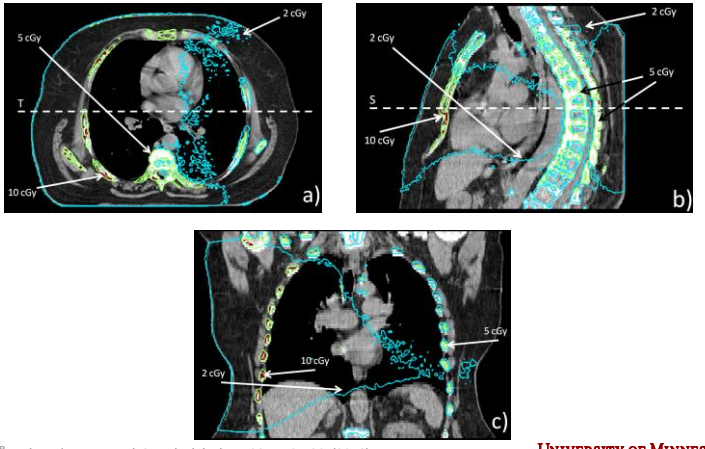
Examples of CBCT dose measurements

- Islam et al. Med. Phys. 33 (1573-1582):
  - Ion chamber and MOSFET measurements on a prototype Elekta XVI unit
- Gayou et al. Med. Phys. 34 (499-506):
  - Ion chamber, film, and TLD measurements on a Siemens unit
- Kan et al. Int. J. Rad. Onc. Biol. Phys. 70 (272-279):
  - TLD measurements on a Varian OBI unit
- Song et al. Med. Phys. 35 (480-486):
  - Ion chamber measurements on both Varian OBI and Elekta XVI units

Methods used for dose calculation

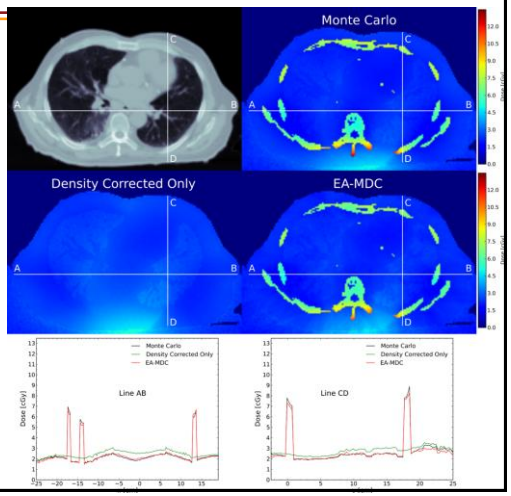
- Monte Carlo Methods:
  - Many papers by multiple authors
- Other Algorithms:
  - Medium-dependent-correction (MDC) algorithm
    - Ding, Pawlowski and Coffey, "A correction-based dose calculation algorithm for kilovoltage x rays", Med. Phys. 35: 5312-5316 (2008)

Example of MC dose calculation



Spezi et al. *Int. J Rad Oncol Biol Phys*, 83: 419-426 (2012)

Example of MDC dose calculation

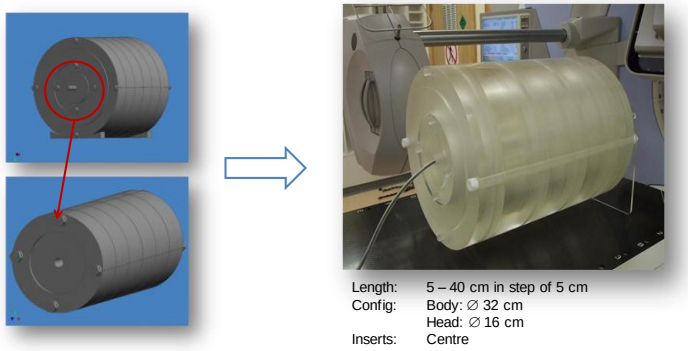


Pawlowski and Ding, *Phys. Med. Biol.* 56: 3919-3934 (2011)

Methodology used to describe the dose

- Absorbed dose in phantom/patient/organ
  - Measuring ionization using a properly calibrated ion chamber at a reference depth in phantom, static or rotational delivery
  - Standard for CBCT dose measurement currently being developed (TG-180)
- CT Dose Index (CTDI)/Cone Beam Dose Index (CBDI)
  - CTDI commonly used for CT dose specification and is a measure of scanner output
  - Standard CTDI phantom not long enough for CBCT beams/longer phantoms needed
  - Longer ionization chamber than the 10 cm pencil one may also be needed

Optimised CBDI phantom



Length:	5 – 40 cm in step of 5 cm
Config:	Body: ∅ 32 cm
	Head: ∅ 16 cm
Inserts:	Centre
	Periphery
Probes:	CC-13, TLD, pencil IC 10 cm

Courtesy Emiliano Spezi, Velindre Cancer Centre, Cardiff, UK

Methodology used to describe the dose

- Expanding the CTDI paradigm to CBCT:
  - Measure the dose at center and periphery
  - $CTDI_{100}$ = D/10 (cm)
  - $CTDI_w$ = (1/3)$CTDI_{100}$(center) + (2/3) $CTDI_{100}$(periphery)
  - $CTDI_{vol}$ = $CTDI_w$/pitch
  - Pitch is 1 for CBCT so $CTDI_{vol}$ = $CTDI_w$

Typical CTDI values

- Varian OBI*
  - Head: 3.9 mGy
  - Pelvis: 17.7 mGy
  - Thorax: 4.7 mGy
- Elekta XVI*
  - Head: 1.0-1.2 mGy
  - Pelvis: 19.9-26.8 mGy
  - Chest: 22.0 mGy
- Siemens TBL**
  - Head: 3.5 cGy
  - Body: 2.5 cGy
- Siemens IBL**
  - Head: 3.3 cGy
  - Body: 2.4 cGy

*Manufacturer documentation
**Fast et al., *Phys. Med. Biol.* 57: N15-N24 (2012)

Methodology used to describe the dose

- Absorbed dose vs. effective dose
  - Due to differences in the distribution of radiation dose from various imaging modalities, conversion of absorbed dose to effective dose is necessary for comparison purposes (TG 75)

Beam data for treatment planning

- Megavoltage imaging: Same as MV beam data collection
- Kilovoltage imaging:
  - Utility of automatic water scanning systems is limited
  - Step-by-step (integrating) depth dose and profile measurements are necessary
  - Measured data may need to be supplemented with MC-generated ones
  - Output factors need to be measured for various imaging techniques

Imaging beam data-Varian OBI

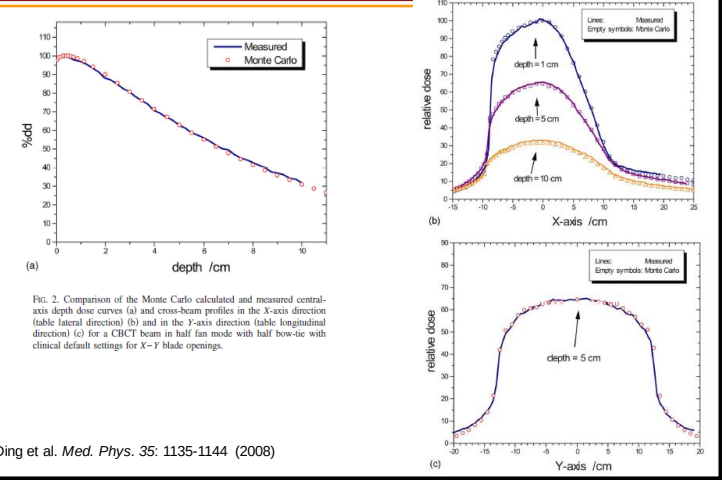
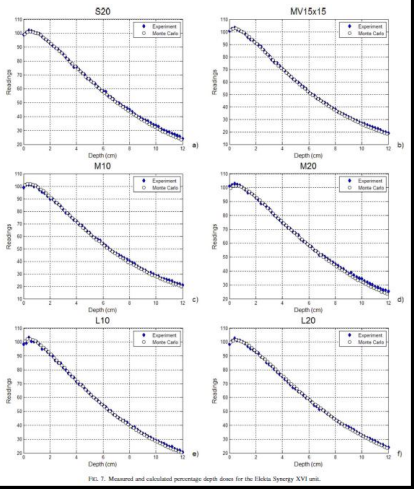


FIG. 2. Comparison of the Monte Carlo calculated and measured central-axis depth dose curves (a) and cross-beam profiles in the *X*-axis direction (table lateral direction) (b) and in the *Y*-axis direction (table longitudinal direction) (c) for a CBCT beam in half fan mode with half bow-tie with clinical default settings for *X*–*Y* blade openings.

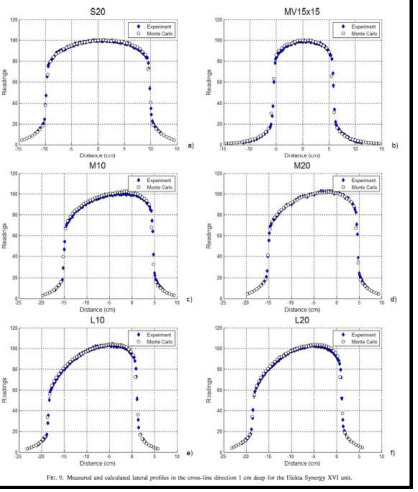
Ding et al. *Med. Phys. 35*: 1135-1144 (2008)

Imaging beam data-Elekta XVI



Spezi et al. *Med. Phys*. 36: 127-136 (2009)

Imaging beam data-Elekta XVI



Spezi et al. *Med. Phys*. 36: 127-136 (2009)

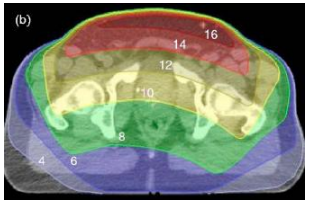
Dose inclusion in treatment plans

- Megavoltage Imaging:
  - The 6 MV Therapy Beam Line (TBL) can easily be added to the treatment plans as an arc
  - The 4.2 MV Imaging Beam Line (IBL) can also be added to the treatment plans but requires beam data collection and TPS modeling and commissioning

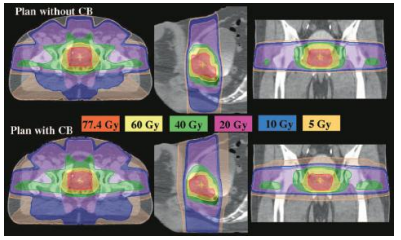
Dose inclusion in treatment plans

- Kilovoltage Imaging:
  - The 100/120 kVp imaging beams requires beam data collection and TPS modeling and commissioning
  - Most planning systems do not accommodate dose calculations in kV range

MV CBCT dose inclusion



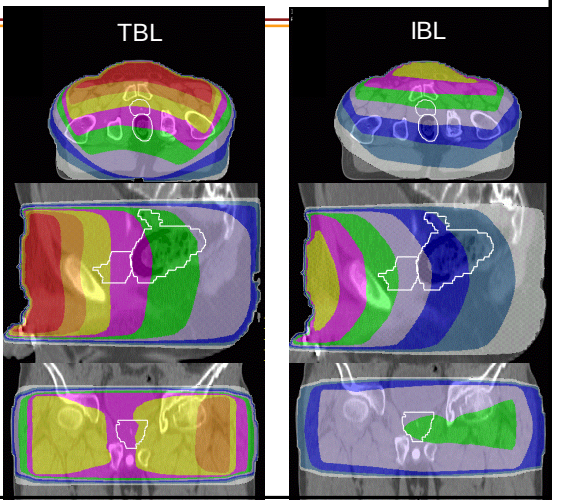
Distribution of dose deposited in the pelvis by a single fraction of CB imaging for a prostate patient, with 10 cGy at isocenter. The isodose lines are labeled in cGy.



Example of isodose distributions 77.4, 60, 40, 20, 10, and 5 Gy on transverse, sagittal, and coronal CT slices from the IMRT plan (upper panel) and the IMRT plan optimized with daily MV-CBCT (lower panel) of a prostate patient. The latter was used for treatment.

21 Miften et al., *Med. Phys*. 34: 3760-3767 (2007)

MV CBCT dose inclusion



Flynn et al., *Med. Phys*. 36: 2181-2192 (2009)

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kV CBCT dose inclusion

- Inclusion of the dose from kilovoltage CBCT in patient treatment plans is more complex, mainly because of inability of commercial treatment planning systems to compute dose in the kilovoltage energy range, and the need for beam data collection

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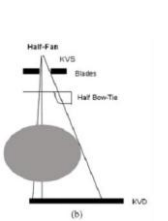
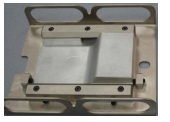
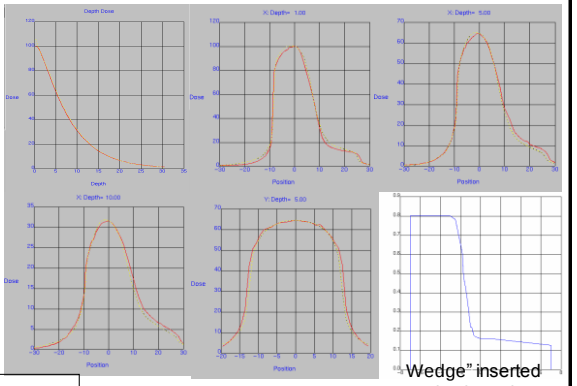
Beam modeling-Varian OBI







Measurement :

Pinnacle:

"Wedge" inserted to simulate shape of profile

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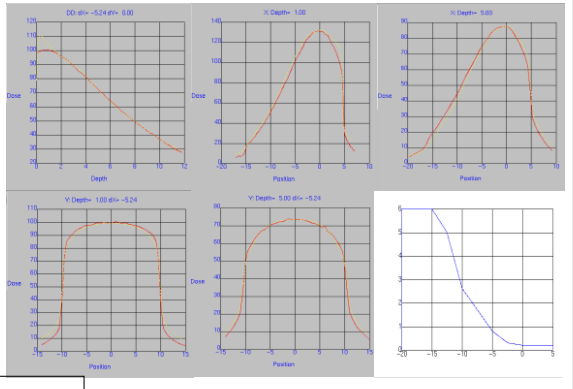
Beam modeling-Elekta XVI

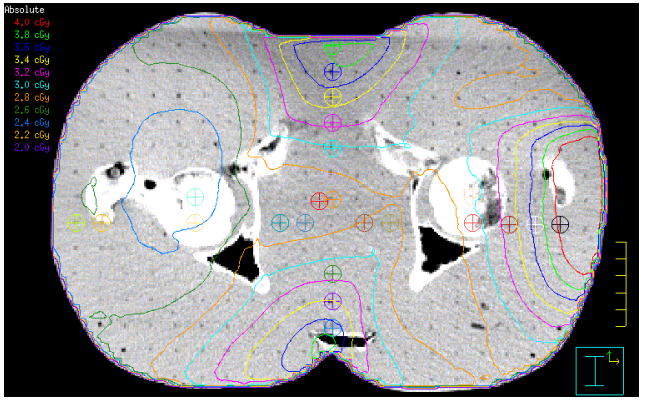
M20 Cassette
F1 Filter



Measurement :

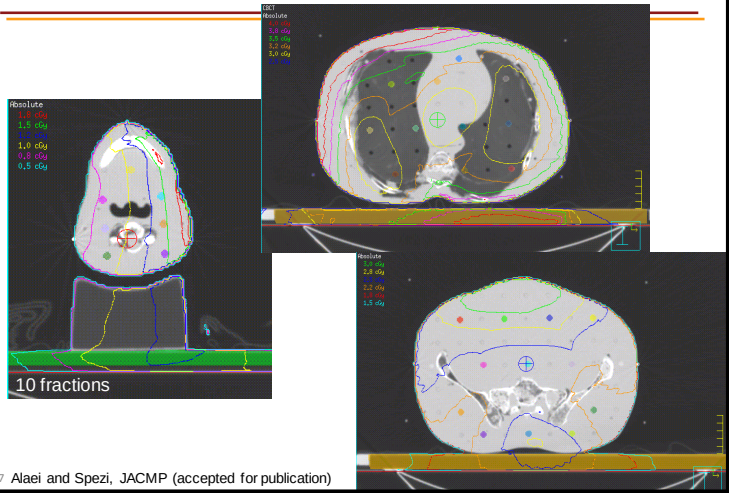
Pinnacle:

Dose calculations-Varian OBI



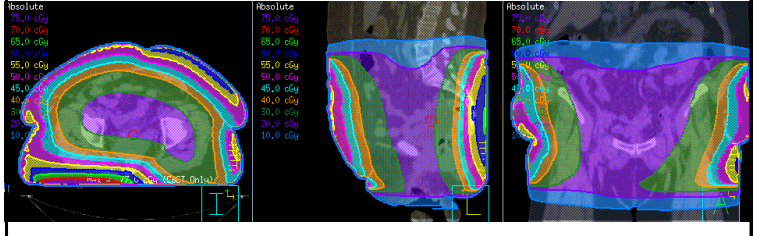
 Alaei et al., *Med. Phys.* 37: 244-248 (2010)

Dose calculations-Elekta XVI



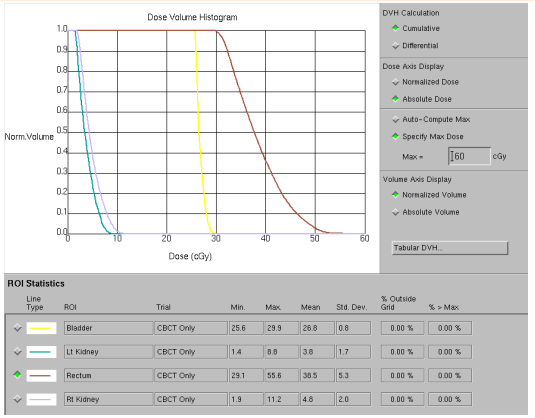
 Alaei and Spezi, JACMP (accepted for publication)

Clinical examples



Dose distribution from ten CBCT acquisitions with the XVI kV source rotating from 180 to 180 degrees (120 kVp, 25 mA, 40 ms, M20 cassette, F0 filter)

Clinical examples

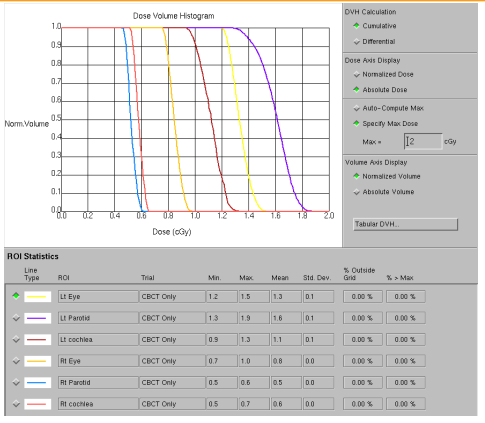


DVH of several organs from ten CBCT acquisitions (120 kVp, 25 mA, 40 ms, M20 cassette, F0 filter)

Clinical examples

Dose distribution from ten CBCT acquisitions with the XVI kV source rotating from 345 to 190 degrees (100 kVp, 10 mA, 10 ms, S20 cassette, F0 filter)

Clinical examples



DVH of several organs from ten CBCT acquisitions (100 kVp, 10 mA, 10 ms, S20 cassette, F0 filter)

Dose inclusion - Conclusions

- Megavoltage Imaging:
  - Easily implemented for therapy beams, may need additional data acquisition/TPS commissioning for additional energies
- Kilovoltage Imaging:
  - Not possible with most TPS systems
  - Requires beam data acquisition and TPS commissioning
  - Limited in accuracy specially in bony anatomy