Accounting for kV Imaging Dose

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kilovoltage imaging devices/techniques

- 2D imaging
  - kV digital radiography (Varian & Elekta)
  - BrainLab ExacTrac
  - Accuray CyberKnife

  } • Imaging dose < 5% threshold, unless there are a large number of images no need to account for
- 3D imaging
  - Cone Beam CT
    - Varian OBI and TrueBeam
    - Elekta XVI
    - Siemens kVision
    - Mitsubishi MHI-TM1000

  } • Imaging dose may be > 5% threshold, depending on protocol may need to account for

Current imaging dose determination methods

- Measurements:
  - Phantom/patient measurements
- Calculation algorithms:
  - Monte Carlo-based
  - Model-based (commercial and non)

Current imaging dose accounting methods

- Patient specific calculations:
  - Need to utilize Monte Carlo or a treatment planning system
  - Not commercially available
- Non-patient specific estimations:
  - Use organ dose "look-up" tables

Imaging dose measurements

- Numerous publications on measurements in phantom
- Generally performed on anthropomorphic phantoms
- Used various type detectors (TLD, film, OSLD, etc.)
- Take note of publication date, older ones have used older versions of imaging hardware and software
- Few publications on measurements in patient, generally skin dose measurements

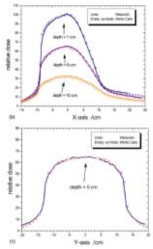
- List of publications: Tables 1 and 2, Alaei and Spezi, *Phys. Med.* 31: 647-658 (2015)

Monte Carlo-based methods

- Monte Carlo is commonly used for simulating both Megavoltage and kilovoltage beams and is often regarded as the gold standard in dose calculations
- Monte Carlo has been extensively utilized to:
  1) Characterize kV imaging systems
  2) Produce and/or verify imaging beam data
  3) Determine imaging doses (in phantom and patient), and generate organ dose tables

MC characterization of kV imaging systems

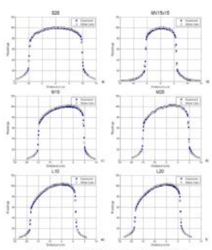
- Varian OBI:
  - Ding et al. *Med. Phys.* 35: 1135-44 (2008)
  - Ding et al. *Phys. Med. Biol.* 55: 5231-48 (2010)
  - Deng et al. *Int. J. Rad. Oncol. Biol. Phys.* 82: 1680-88 (2012)



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

MC characterization of kV imaging systems

- Elekta XVI:
  - Chow et al. *Med. Phys.* 35: 52-60 (2008)
  - Spezi et al. *Med. Phys.* 36: 127-36 (2009)
  - Downes et al. *Med. Phys.* 36: 4156-67 (2009)



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

Model-based methods

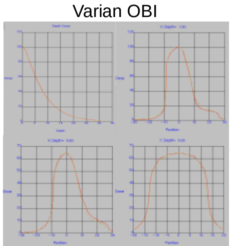
- Commercial Treatment planning systems
  - Not yet capable to compute the dose from kilovoltage beams
  - Requires development of new algorithms that can account for atomic number changes
  - Even if this capability is established will require imaging beam data collection and commissioning
  - Currently limited to one system in the research setting with inherent inaccuracies

Model-based methods-Commercial TPS

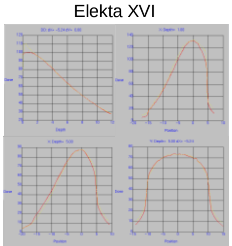
- Pinnacle TPS with addition of low energy kernels (not included with the commercial system)
- Varian OBI, Elekta XVI, and Siemens kVision imaging beams modeled
- Beam data obtained via measurements and/or MC simulations
- Has been used to compute dose to phantom and patients
- Dose in soft tissue is of sufficient accuracy but that in bone underestimated by up to 300%

Model-based methods-Commercial TPS

Varian OBI



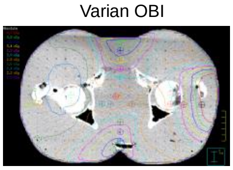
Elekta XVI



Measured :
Modeled:

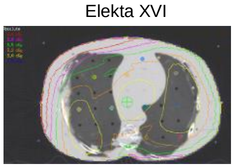
Model-based methods-Commercial TPS

Varian OBI



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

Elekta XVI

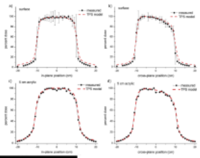


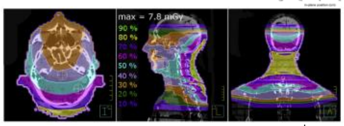
Alaei and Spezi, *J. Appl. Clin. Med. Phys.* 13, 19-33 (2012)

*Bone dose not accurate

Model-based methods-Commercial TPS

Siemens kVision





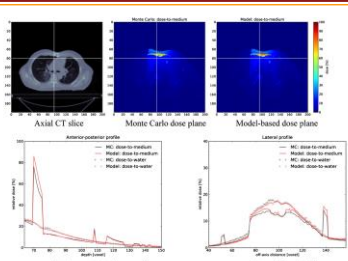
13 Dzierma et al. *Int. J. Rad. Oncol. Biol. Phys.* 88: 913-919 (2014) *Bone dose not accurate

Model-based methods

- Non-commercial systems
  - Medium-dependent-correction (MDC) algorithm*
    - Overcomes the shortcoming of model-based algorithms commonly employed in commercial TPS by accounting for atomic number changes
    - Has the potential for computing dose from kV beams with an accuracy of 10-20%

*Ding et al. *Med. Phys.* 35: 5312-5316 (2008)

Model-based methods-Non-commercial

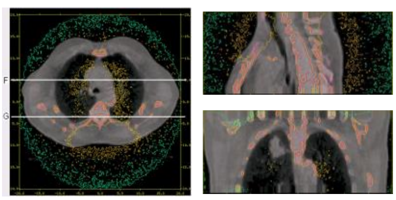


15 Pawlowski and Ding, *Phys. Med. Biol.* 59: 2041-2058 (2014)

Imaging dose accounting methods

- Patient-specific
  - Use Monte Carlo – not possible in clinical practice
  - Use TPS – not possible routinely, has accuracy limitations
  - Maybe in the future and if warranted

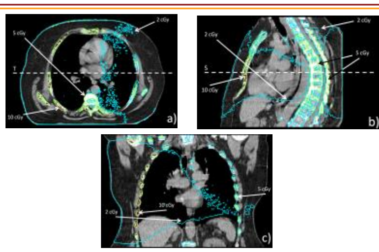
Patient specific calculations



Monte Carlo-computed dose, Varian OBI

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

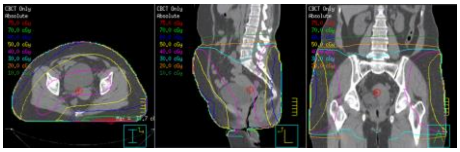
Patient specific calculations



Monte Carlo-computed dose, Elekta XVI

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

Patient specific calculations



Imaging dose from 25 fractions of pelvic imaging using Elekta XVI pelvis imaging protocol (120 kVp, 1 mAs, 650 projections), calculated using Pinnacle TPS

Alaei et al. *Acta Oncol.*, 53: 839-844 (2014)

Imaging dose accounting methods

- Non-patient specific
  - Use tables of dose values for different systems and techniques
    - Typical organ doses provided in TG-180 report
  - When using such tables note the protocol used (kV, mAs, half vs. full fan, bowtie filter) as well as software version
  - Scale the dose values with the mAs used for image acquisition

Non-patient specific estimation

Varian OBI 1.4, half fan, 125 kVp, 700 mAs, 360 degree gantry rotation

Pelvic Scan, prostate isocenter		
Organ	D50 range (cGy)	D10 range (cGy)
(a)		
Bladder	1.36–2.20	1.72–2.69
Bowel	1.54–1.91	2.04–2.65
Femoral Heads	2.40–3.37	3.16–4.62
Prostate	1.19–1.79	1.33–1.89
Rectum	1.51–1.99	1.70–2.22
Skin	1.80–1.96	2.26–2.92
Bones	2.93–3.96	4.61–5.72

Varian OBI 1.4, half fan, 110 kVp, 262 mAs, 360 degree gantry rotation

Low-dose Thorax		
Organ	D50 range (cGy)	D10 range (cGy)
Aorta	0.42–0.58	0.44–0.63
Lungs	0.30–0.63	0.43–0.72
Small Bowel	0.33–0.54	0.39–0.61
Esophagus	0.29–0.60	0.35–0.74
Kidney	0.43–0.54	0.49–0.59
Heart	0.31–0.55	0.41–0.63
Liver	0.31–0.51	0.38–0.61
Spinal Cord	0.32–0.54	0.35–0.78
Spleen	0.32–0.52	0.36–0.60
Stomach	0.28–0.57	0.31–0.62
Trachea	0.36–0.71	0.47–1.04
Skin	0.46–0.57	0.64–0.89
Bones	1.06–1.74	1.47–2.25

Nelson and Ding, *Radiother. Oncol.* 112: 112-118 (2014)

Non-patient specific estimation

Elekta XVI, 120 kVp, 1.6 mAs per acquisition

Pelvis 1	PTV	Rectum	Left femoral head	Right femoral head	Body
M20 F0	3.1	2.1	4.7	6.2	3.3
M20 F1	2.4	1.5	3.4	4.3	2.1
M15 F0	2.9	1.8	4.3	5.8	2.9
M15 F1	2.3	1.3	3.1	4.0	1.8
M10 F0	2.8	1.5	3.9	5.4	2.4
M10 F1	2.1	1.1	2.8	3.7	1.5
Pelvis 2					
L20 F0	1.4	1.7	3.1	3.9	2.4
L20 F1	1.1	1.3	2.2	2.7	1.4
L10 F0	1.2	1.6	2.9	3.5	1.9
L10 F1	1.0	1.1	2.0	2.5	1.1

Chest 1	PTV	Spinal cord	Spinal cord PRV	Left lung	Right lung	Heart	Body
M20 F0	5.1	1.7	3.8	2.2	2.9	2.7	3.1
M20 F1	2.9	1.2	2.6	1.5	2.0	2.0	2.0
M15 F0	4.9	1.4	3.0	2.0	2.7	2.5	2.5
M15 F1	2.7	1.0	2.1	1.4	1.8	1.9	1.6
M10 F0	4.6	1.1	2.4	1.7	2.4	2.2	2.0
M10 F1	2.5	0.8	1.6	1.2	1.6	1.7	1.2
Chest 2							
M20 F0	4.6	2.2	4.8	2.9	4.0	3.0	3.4
M20 F1	3.5	1.5	3.1	1.7	2.9	2.2	2.2
M15 F0	4.1	1.5	3.4	2.4	3.4	2.7	2.4
M15 F1	3.1	1.0	2.2	1.4	2.5	1.9	1.5
M10 F0	3.8	1.2	2.6	2.0	3.0	2.4	1.8
M10 F1	2.9	0.8	1.7	1.2	2.2	1.7	1.2

Elekta XVI, 100 kVp, 0.1 mAs per acquisition

Head and neck 1	PTV	Spinal cord	Spinal cord PRV	Mandible	Right parotid	Left parotid	Left eye	Right eye	Body
S20 F0	0.32	0.17	0.36	0.83	0.27	0.27	0.11	0.10	0.21
S10 F0	0.31	0.12	0.25	0.45	0.03	0.05	0.01	0.01	0.12

Head and neck 2	PTV1	Spinal cord	Spinal cord PRV	Brainstem	Left parotid	Larynx	Left eye	Right eye	Oral cavity	Left PTV2	Right PTV2	Body
S20 F0	0.32	0.16	0.32	0.15	0.27	0.28	0.18	0.18	0.38	0.32	0.37	0.23
S10 F0	0.24	0.13	0.25	0.03	0.15	0.26	0.01	0.01	0.17	0.26	0.08	0.10

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

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Conclusions

- Accounting for kV imaging is generally not necessary for 2D imaging and low dose CBCT protocols (i.e. H&N)
- It may be necessary if high dose CBCT protocols are used and/or due to imaging frequency
- Monte Carlo and model-based methods are not currently available for routine clinical use, hence not feasible to perform patient specific calculations
- Tables of organ doses are an alternative and can be used for non-patient specific estimations

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