Weighing the risks and benefits of imaging guidance with ionizing radiation

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Disclosures

Over the years in doing my research work I have received research grands from:

- National Institutes of Health (NIH)
- Varian Medical Systems
- BrainLab

The commercial products mentioned in this presentation do not represent any endorsement of one product or manufacturer over another

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Learning Objectives

1. Learn the magnitude of typical organ doses resulting from different imaging procedures and modalities
2. Learn available techniques to reduce the imaging dose in daily clinical practice
3. Learn methods to account for imaging dose
4. Develop a perspective view of organ doses from imaging procedures relative to therapeutic beams.
5. Understand weighing the risks and benefits of imaging guidance for effective target localization.

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Outline

1. Background and sources of radiation to patient organs
2. Magnitude of typical organ doses resulting from different imaging procedures
3. Methods to account imaging dose and techniques to reduce them
4. A perspective view of radiation to sensitive organs between imaging dose and unintended dose from therapeutic beams.
5. Weighing the risks and benefits of imaging guidance

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Background

- Ionizing radiation is used to treat cancer: Radiotherapy
- Ionizing radiation also causes cancer: As Low As Reasonably Achievable (ALARA principle)
- Benefits of IGRT
  - Improving the geometric accuracy of patient positioning for radiation delivery
  - Enabling highly conformal target treatment
  - Monitoring treatment target changes for potential adapted treatment
- Risks of imaging
  - Secondary cancer
  - Organ dose tolerance
  - Precisely treating the wrong target
- Guidelines of balancing the benefits and risks: the AAPM TG-180

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Sources of radiation to healthy tissues

- Therapeutic radiation beams aiming to the target is accompanied by unwanted dose to organs outside the target
- These doses to healthy organs are unavoidable
- Sources of unwanted dose:
  - Primary beams to healthy organs that near the target
  - Out-of-field doses from the leakage and scatter
  - X-ray imaging
- Treatment planning: minimizing the dose to heathy tissue
- Imaging: minimizing the error of target positioning

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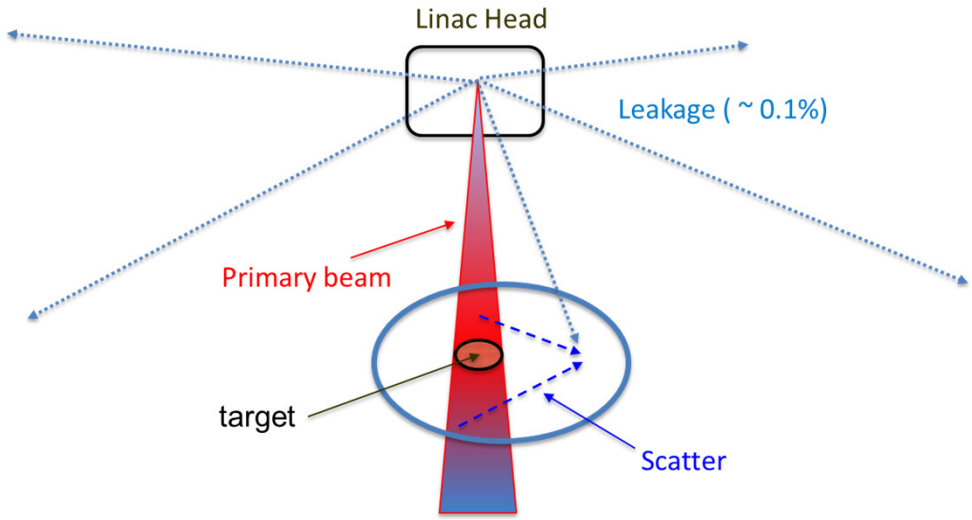
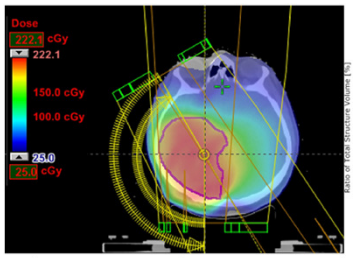
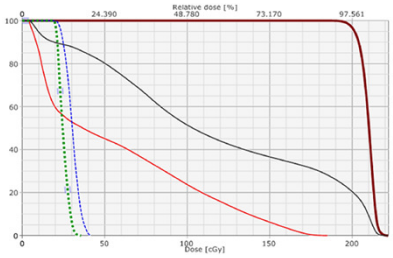
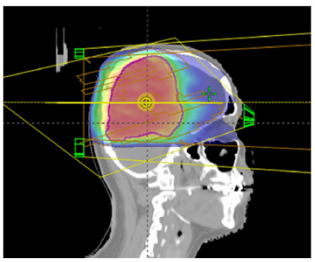
Unwanted Dose to Healthy Tissues

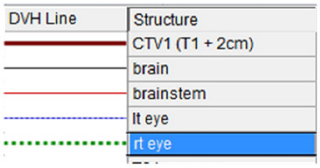


Unavoidable dose from therapeutic beams









Target dose: 200 cGy; Brain stem: 50 cGy; Eyes: 30 cGy

Dose from x-ray imaging

- MV electronic portal imaging device (EPID)
  - 2D images: portal images
  - 3D images: MV-CBCT, MVCT
- kV x-ray devices integrated to treatment unit
  - 2D images: digital radiographs
  - 3D images: kV-CBCT

Dose from x-ray imaging

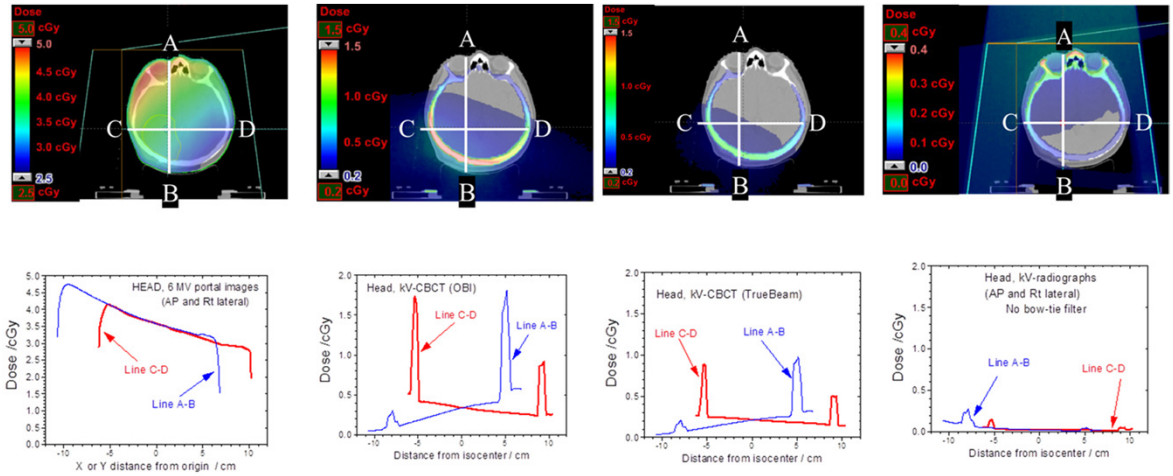
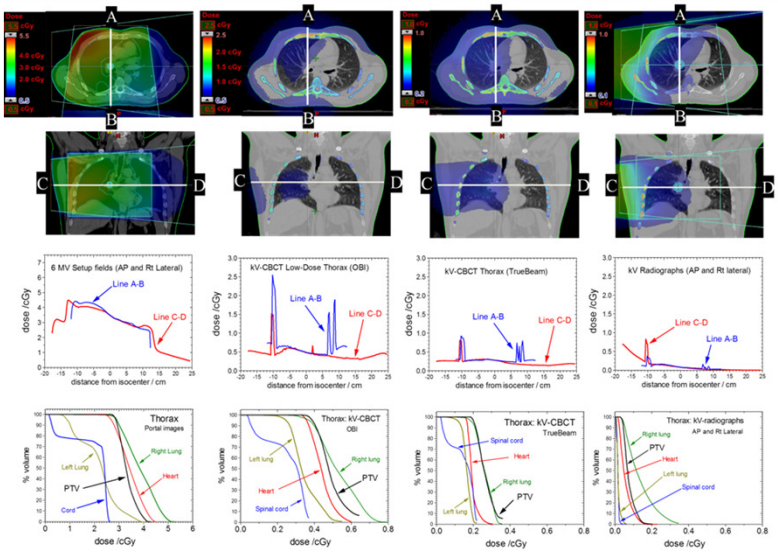


Figure 2 MV portal images: 3 cGy; kV-CBCT scan: 0.2 cGy; kV radiographs: 0.1 cGy

From Ding and Munro 2013, Radiother Oncol 108 (1):91-8

Dose dependency on beam energies and acquisition techniques



From Ding and Munro 2013, Radiother Oncol 108 (1):91-8

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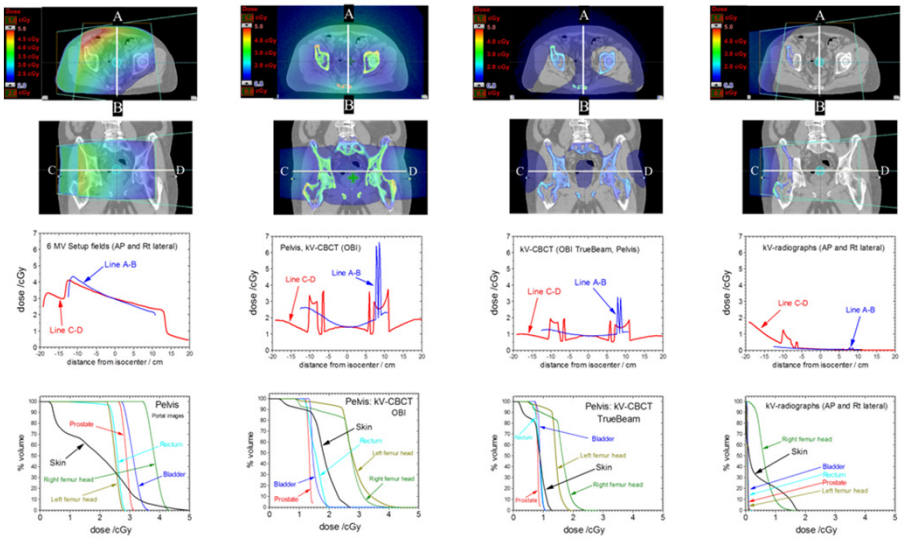
Dose dependency on beam energies and acquisition techniques



From Ding and Munro 2013, Radiother Oncol 108 (1):91-8

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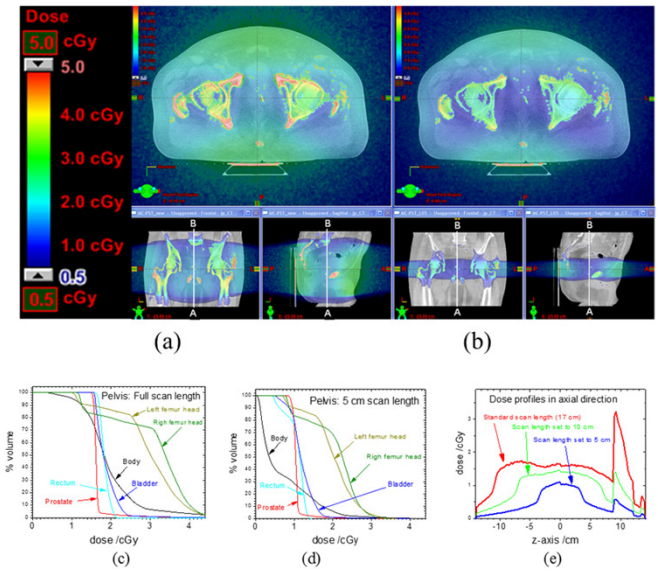
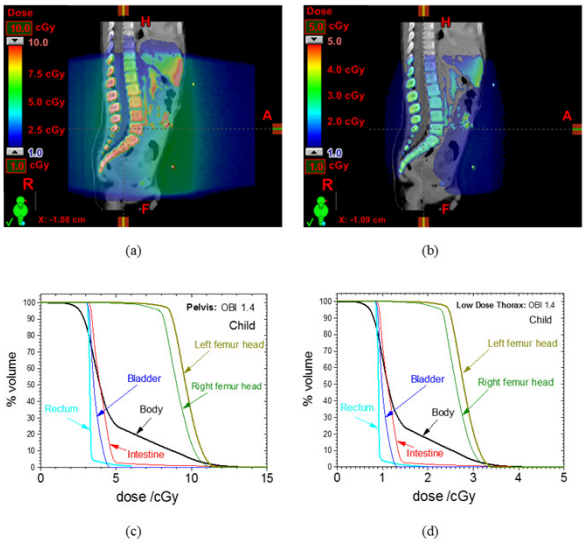
Techniques to reduce the imaging dose

- Using kV beam if it is available
- Select “Image during treatment” to avoid adding additional dose to the patient
- Customizing the imaged volume to the clinical need
- Using 2D radiographs over 3D volumetric images
- Optimize imaging geometry
- Adjust beam entry and exit points during image acquisitions

Reducing imaged region of interest



The effect of using different image protocols



(a) (b)

(c) (d)

(Ding et al. 2010, Radiother Oncol 97 (3):585-92

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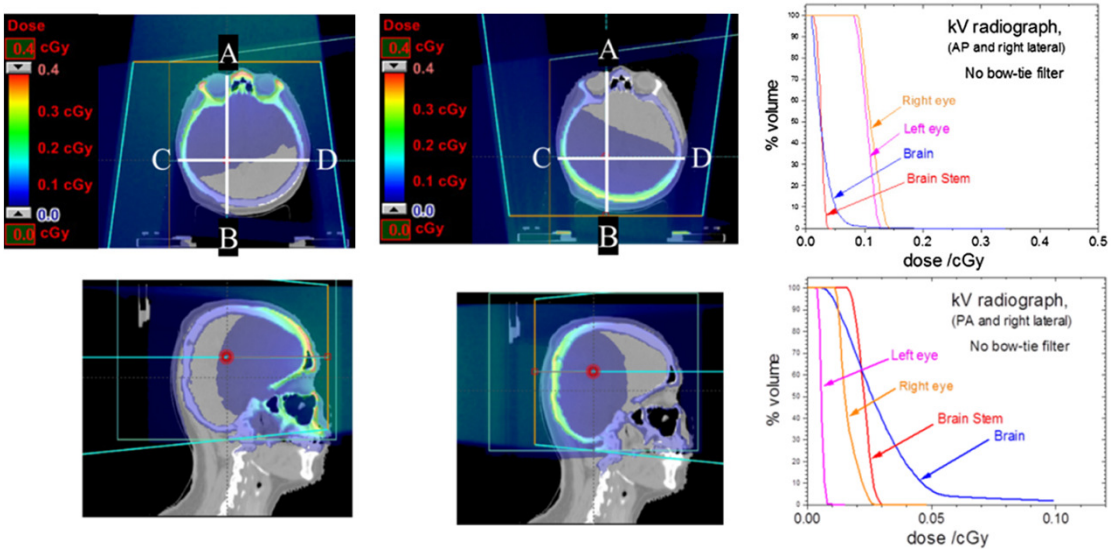
The effect of beam orientation on the doses for a paired kV



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When to account: Dose threshold

- TG-180 recommended imaging dose threshold is
  - 5% of the therapeutic target dose
  - beyond which imaging dose should be considered in the treatment planning process
- Considerations:
  - evidence from published clinical data
  - dose variations that lead to changes in tumor response and the risk of morbidity
  - accuracy requirements in radiotherapy have recommended an accuracy level of ±5% in the delivery and determination of dose to tumors and normal tissue

Account for imaging dose

Two methods are recommended in TG-180 to estimate the dose resulting from imaging procedures

- Method 1: Patient specific imaging dose calculations
- Method 2: Non-patient specific imaging dose estimations

Method 1: Patient specific dose calculation

- Advantages:
  - Individual patient CT based image dose calculation
  - Accurate organ dose calculations from image procedures
  - It can be calculated in a treatment planning system when the therapeutic MV beams are used for imaging
- Disadvantages:
  - It needs details of imaging beam information for dose calculations
  - It is not available in commercial treatment planning systems and requires Monte Carlo techniques for kV beam dose calculations

Method 2: Non-patient specific imaging dose estimations

- Advantages:
  - It is simple and provides clinicians with adequate estimates of imaging dose to organs.
  - It estimates the organ dose based on tabulated values.
  - It only requires the knowledge of the image procedure used as the tabulated dose values are specific to the image protocols.
- Disadvantages
  - It is an estimate and is applicable for small magnitude of imaging dose
  - It is not patient specific.
  - It dose not provide dose distributions

Examples of tabulated image dose to organs

Table 9.1a: Organ doses for the head & neck and brain treatment sites from Varian OBI v1.4 using Standard Head kV-CBCT scan. D50 and D10 are minimum dose delivered to 50% and 10% of the organ volume respectively. (from AAPM TG-180)

Standard Head, Brain				Standard Head, Head & Neck		
Organ	D50 Range (cGy)	D10 Range (cGy)		Organ	D50 Range (cGy)	D10 Range (cGy)
Brain	0.21-0.33	0.27-0.40		Brain	0.15-0.22	0.16-0.23
Brainstem	0.19-0.30	0.22-0.32		Larynx	0.21-00.29	0.25-0.33
Chiasm	0.08-0.26	0.09-0.26		Oral Cavity	0.13-0.26	0.20-0.31
Eyes	0.03-0.31	0.04-0.35		Parotids	0.26-0.42	0.31-0.48
Optic Nerves	0.05-0.27	0.05-0.27		Spinal Cord	0.16-0.25	0.19-0.32
Pituitary	0.07-0.24	0.08-0.25		Thyroid	0.07-0.23	0.11-0.32
Spinal Cord	0.26-0.33	0.29-0.34		Esophagus	0.07-0.16	0.14-0.26
Skin	0.19-0.41	0.39-0.63		Skin	0.18-0.27	0.34-0.44
Bones	0.45-1.11	1.13-1.67		Bones	0.25-0.65	0.64-1.07

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Examples of tabulated image dose to organs

Table 9.2a: Organ doses for the head & neck treatment site from Elekta XVI kV-CBCT scan using S cassettes, 100 kVp, 0.1 mAs/acquisition, 360 acquisitions, 345-190 degree (IEC) rotation. (from AAPM TG-180)

Head and Neck	
Organ	D50 Range (cGy)
Brainstem	0.06-0.08
Rt Eye	0.08-0.09
Lt Eye	0.13-0.13
Rt Parotid	0.05-0.06
Lt Parotid	0.16-0.17
Rt Cochlea	0.04-0.05
Lt Cochlea	0.09-0.12
Oral Cavity	0.09-0.11

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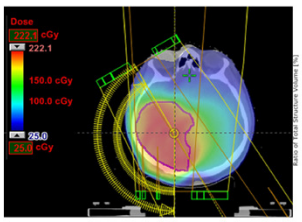
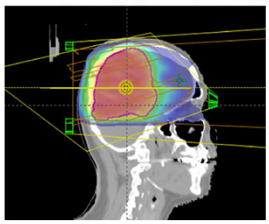
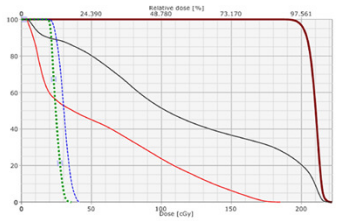
A perspective view on dose to healthy tissues

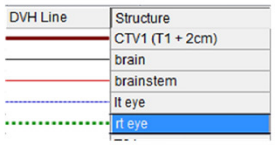
- Unwanted dose from therapeutic beams is generally higher than from the imaging dose
- kV imaging dose is lower than MV imaging dose
- Unwanted doses from therapeutic beams are minimized during treatment planning
- Need a strategy to manage imaging dose

Example of doses to sensitive organs from different sources









Target dose: 200 cGy;
Brain stem: 50 cGy;
Eyes: 30 cGy

Dose to organ-at-risk eyes
(4 -7 cm between target and eyes):

From out-of-field: **25 – 31 cGy**
(12 - 15% of the target dose

MV portal images: **2 – 5 cGy**

kV-CBCT scan: **0.1 – 0.3 cGy**

kV radiographs: **0.05 – 0.1 cGy**

A perspective view on imaging dose healthy tissues

- Unwanted dose from therapeutic beams is generally higher than from the imaging dose
- kV imaging dose is lower than MV imaging dose
- Unwanted doses from therapeutic beams are minimized during treatment planning
- The strategy to manage imaging dose: AAPM TG-180

Weighing the risks and benefits of imaging guidance

- Purpose of imaging during IGRT
  - To ensure the planned dose to the targets accurately
- Risks of imaging
  - Secondary cancer and organ dose tolerance
- Risk of not imaging or imaging incorrectly
  - Large positioning uncertainty or precisely treating the wrong target
- Balancing them to benefit the patient!

Summary

Balancing ALARA principles with the requirement for effective target localization, however, requires that imaging dose be managed on the consideration of weighing risks and benefits to the patient.

-from AAPM TG-180