ACCOUNTING FOR IMAGING DOSE IN TREATMENT PLANS AND AAPM RECOMMENDATIONS

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Disclosures

- Nothing to disclose
- Any reference to commercial products does not imply endorsement

Outline

- Introduction
- Accounting for Imaging Dose in Treatment Plans
- AAPM Recommendations
- Summary and Conclusions

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Introduction

- Do we need to account for imaging dose in treatment plans?
- Perhaps, but we cannot easily do it
- In the case of high imaging doses (i.e. MV imaging), this is often possible

Introduction

- In the case of kV imaging, this is not possible in most instances
- BUT, we can often estimate the imaging dose

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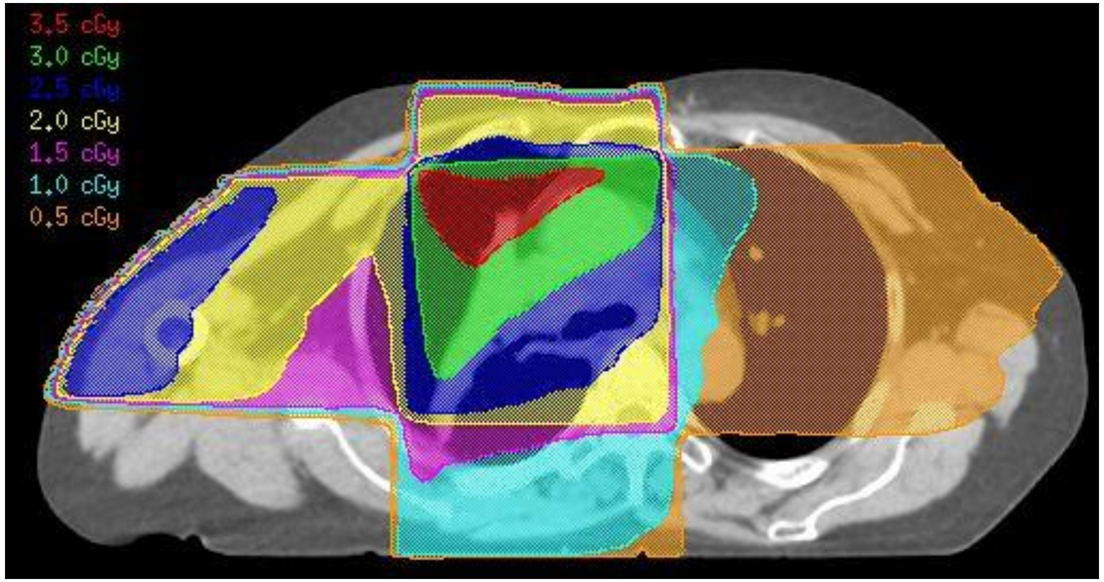
Accounting for Imaging Dose in Treatment Plans

- Feasibility of imaging dose calculations in Treatment plans:
  - Megavoltage portal imaging
  - Megavoltage CBCT & CT
  - kilovoltage CBCT

The following slides refer to studies computing imaging dose using treatment planning systems

MV Portal Imaging

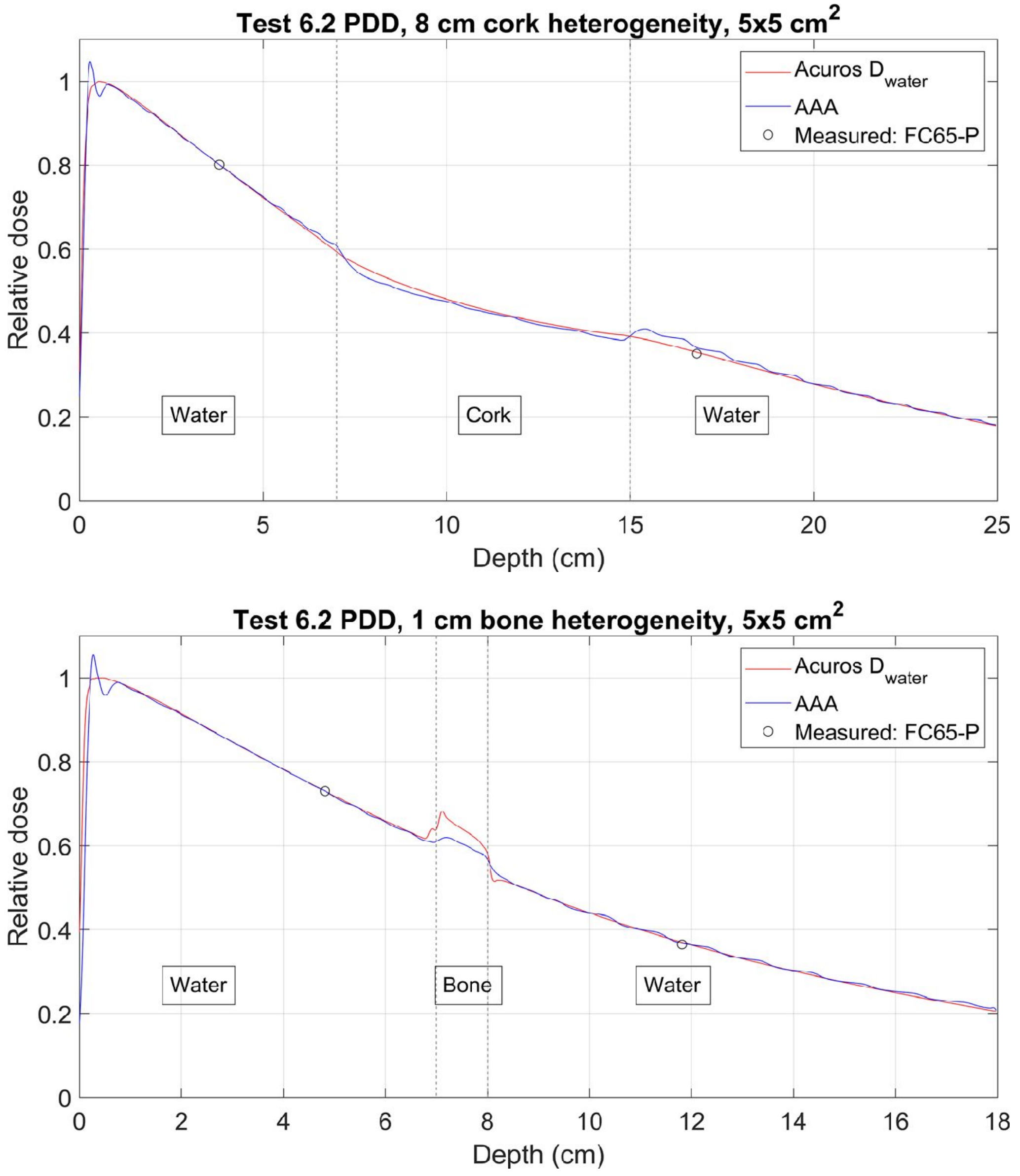
- Including 6 MV portal imaging dose in TPS a straightforward process, if the MUs delivered are known
- This is commonly not done due to low dose



MV Portal Imaging

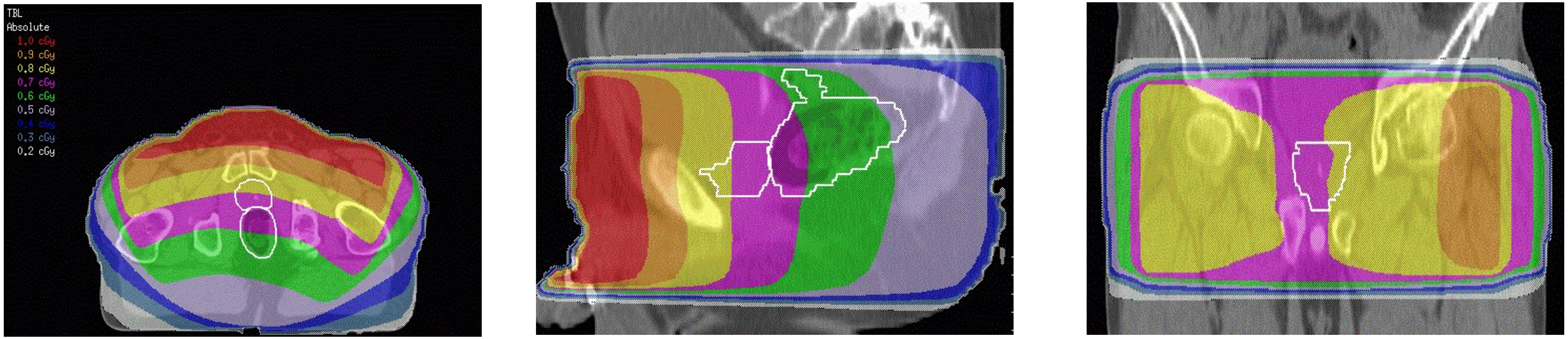
- In this study Eclipse (AXB and AAA algorithms) was commissioned for dose calculations from 2.5 MV imaging beam using collected beam data

- Agreement between calculations and measurements was within 20%

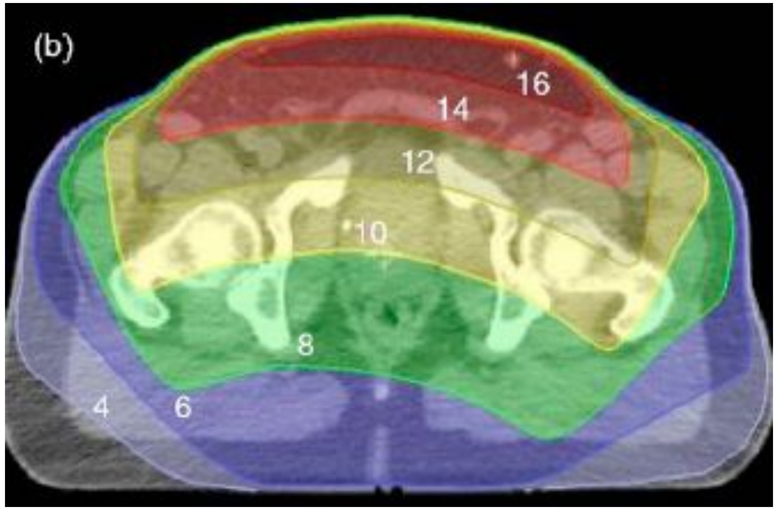


MV CBCT

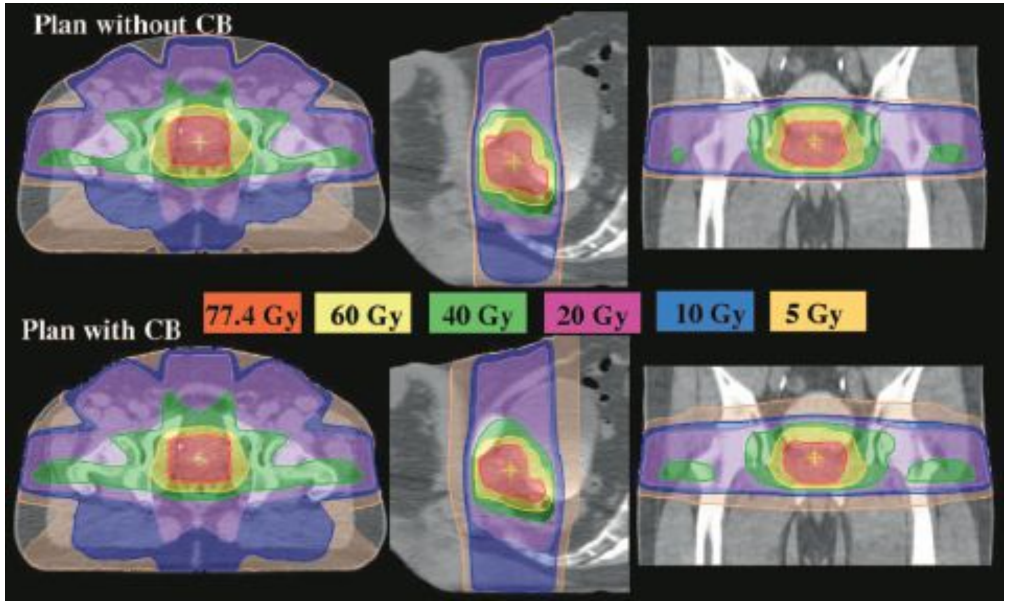
- Including 6 MV CBCT imaging dose in TPS is a straightforward process as it is the beam used for treatment



MV CBCT



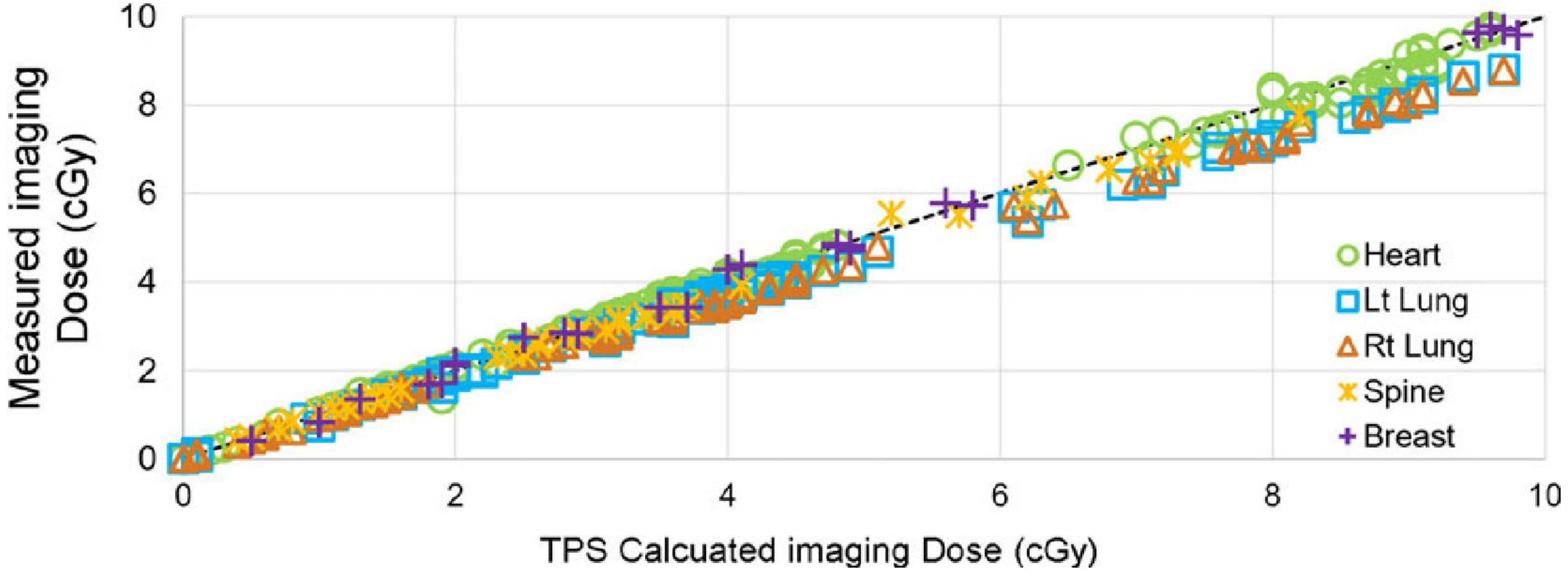
Distribution of dose deposited in the pelvis by a single fraction of CB imaging for a prostate patient, with 10 cGy at isocenter. The isodose lines are labeled in cGy.



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.

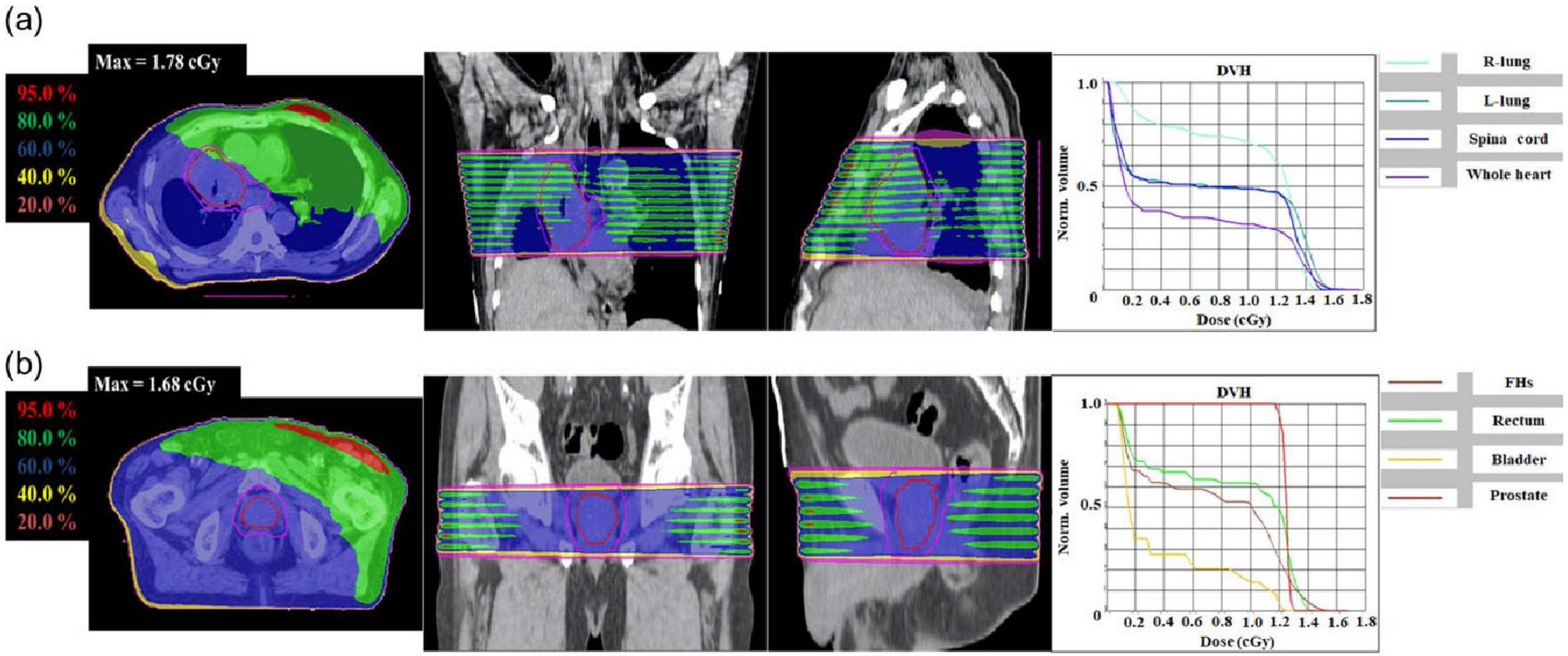
MV CBCT

- In this study Halcyon 6 MV FFF beam dose was calculated in Eclipse (AAA)
- Normal tissue doses calculated and compared to measurements (agreement within 0.5%)



MV CT

- In this study TomoTherapy MV CT (3.5 MV FFF) beam data was collected and used for dose calculation in Pinnacle TPS
- Calculated and measured doses differed by up to 10%



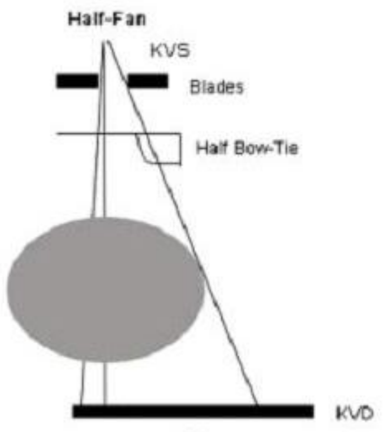
Summary of MV Dose Calculations

- Any megavoltage imaging beam can be modeled and commissioned in treatment planning systems for imaging dose calculations; <u>however</u>, this may need beam data collection

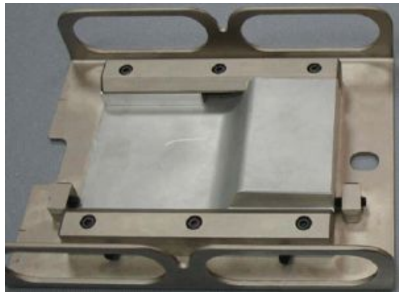
kV CBCT

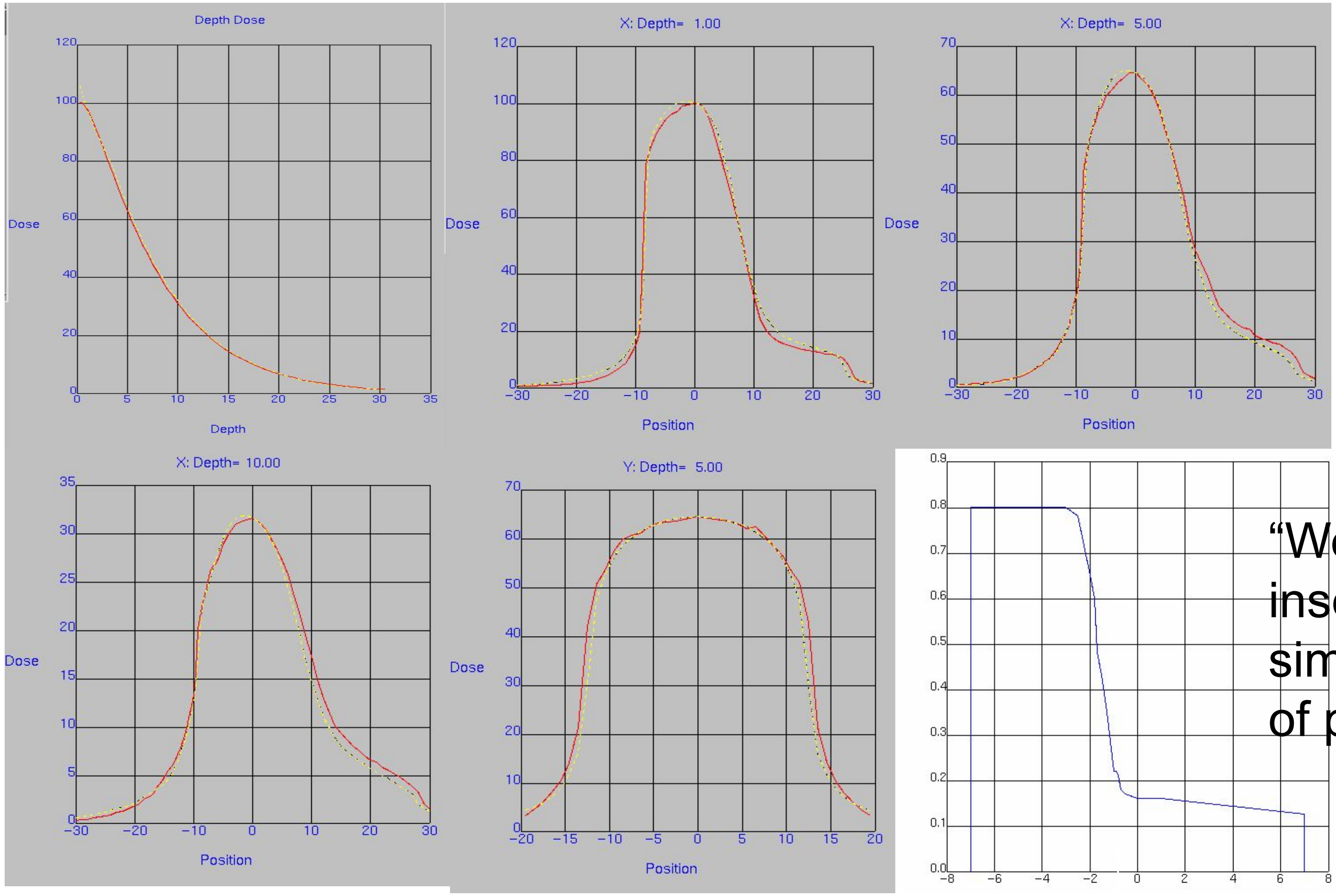
- Kilovoltage imaging beams cannot currently be included in the treatment plans due to inability of commercial TPS algorithms to compute dose at this energy range
- This has *only* been done in research environment using one TPS and requires beam data collection and modeling
- These could potentially be modeled in MC-based systems

Beam Modeling-Varian OBI



(b)





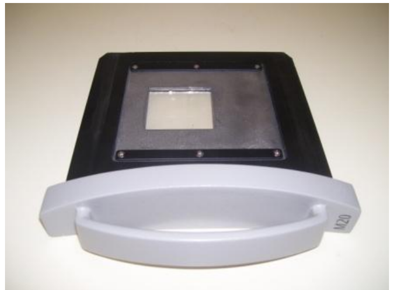
“Wedge” inserted to simulate shape of profile

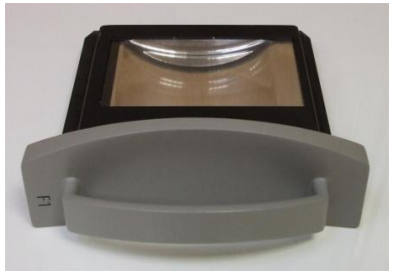
Measurement :

Pinnacle:

Beam Modeling-Elekta XVI

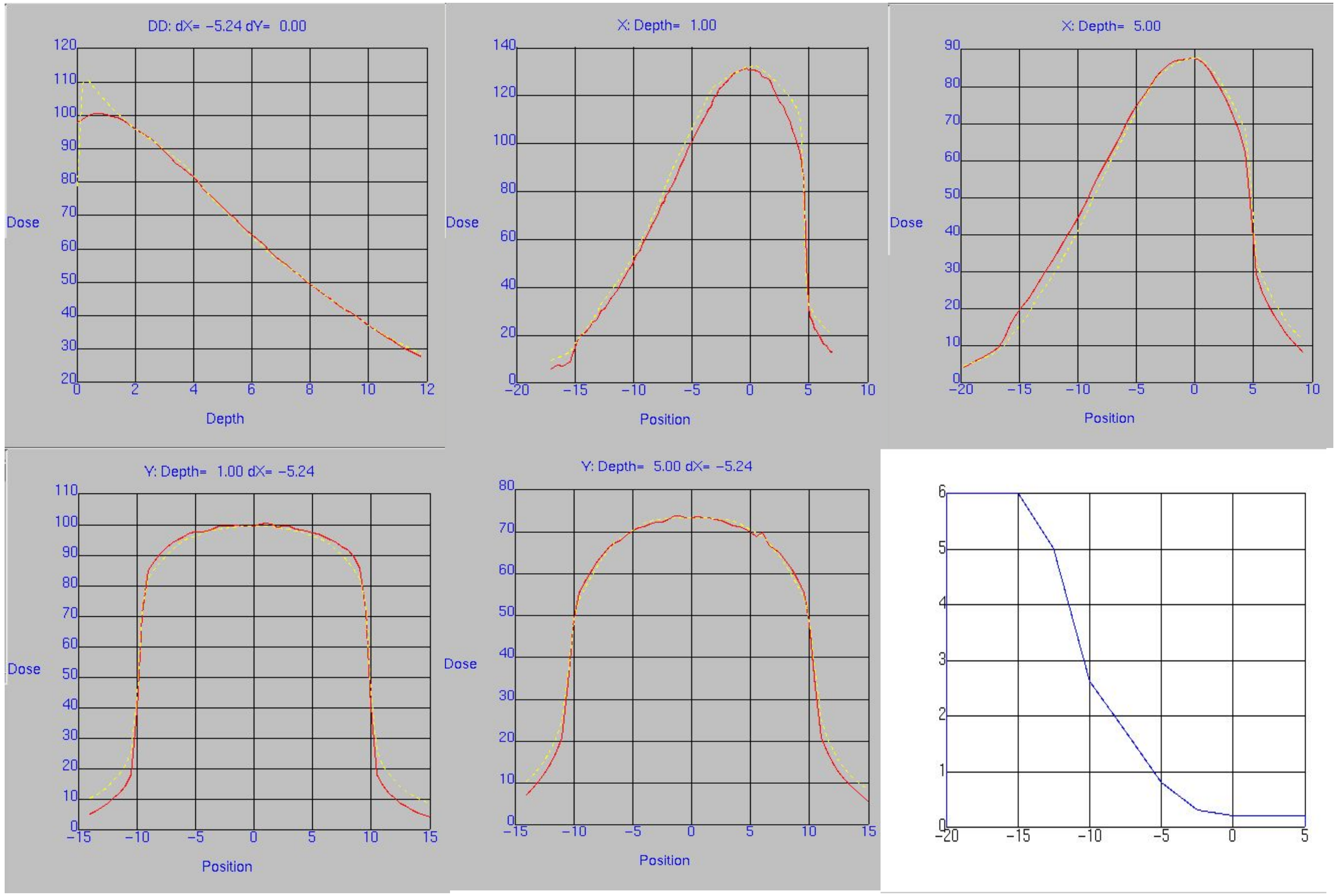
M20
Cassette
F1 Filter



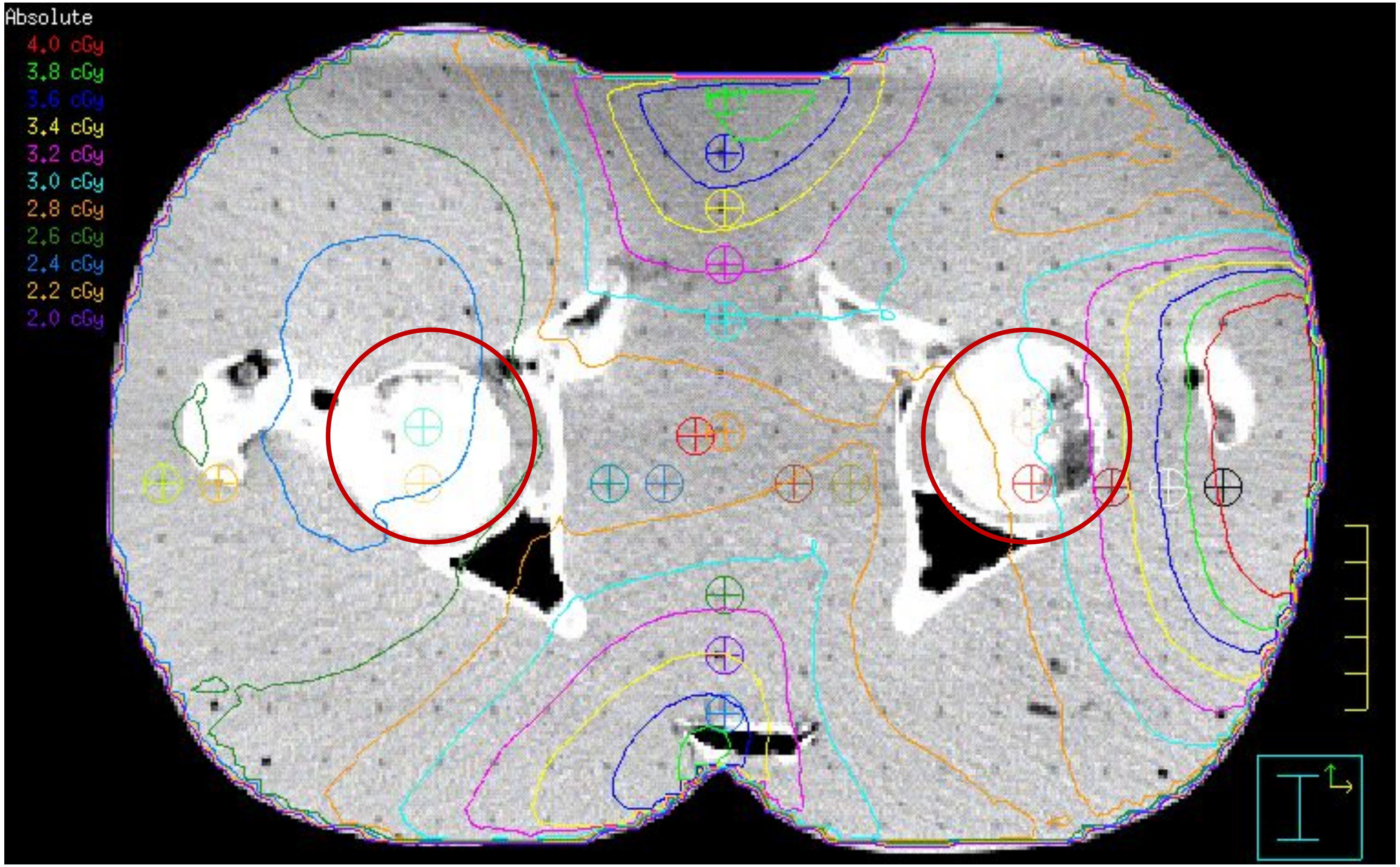


Measurement :

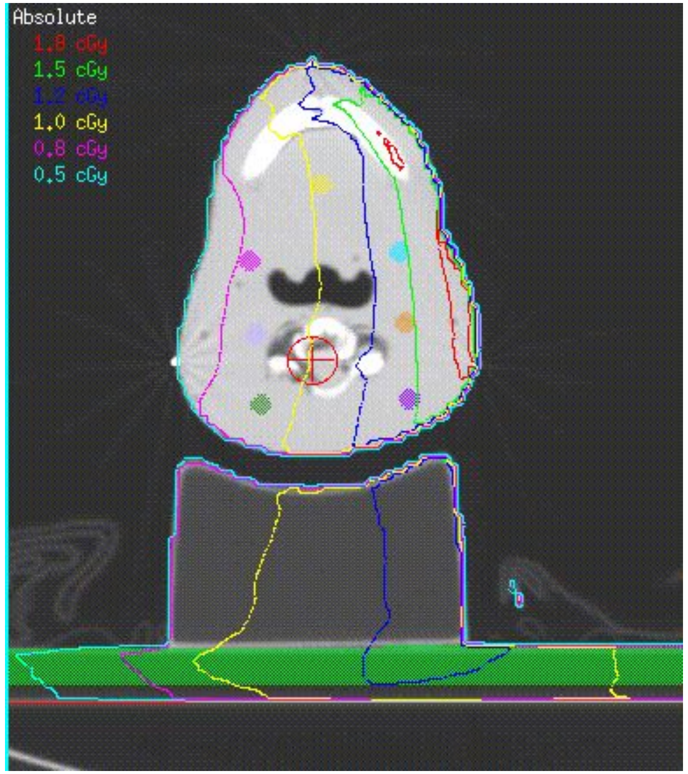
Pinnacle:

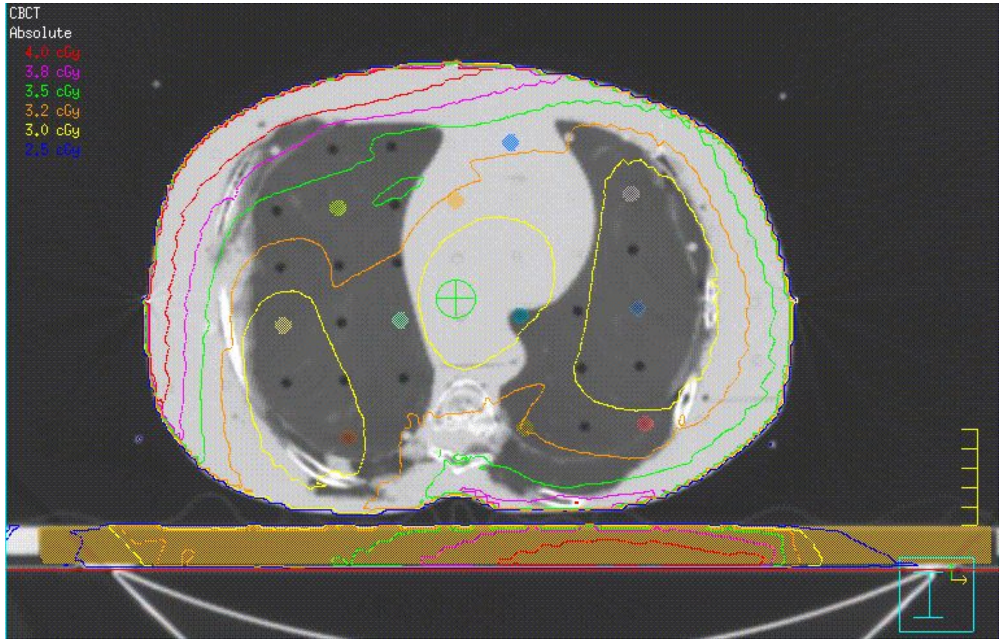


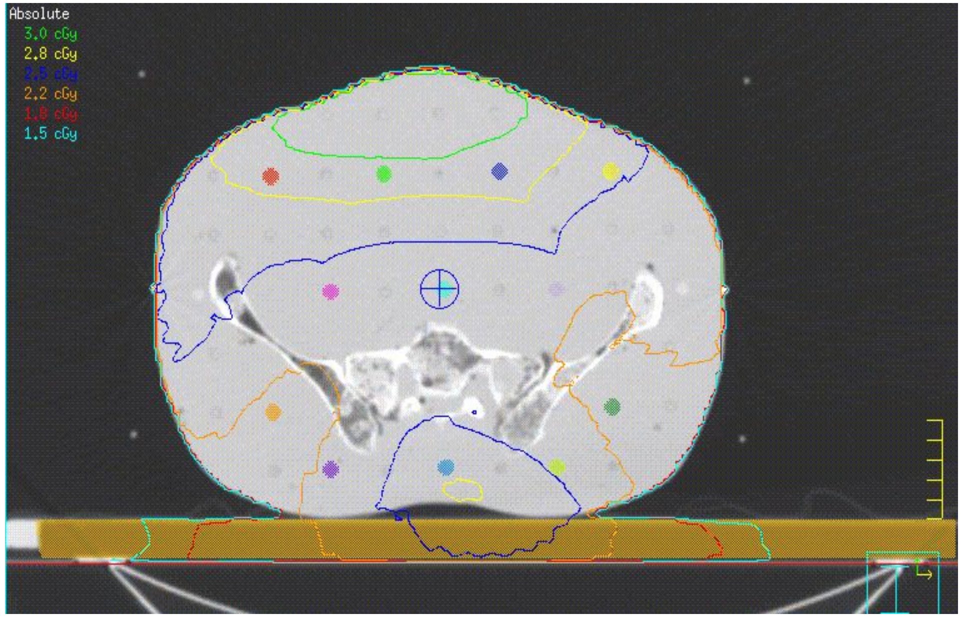
Dose Calculations-Varian OBI

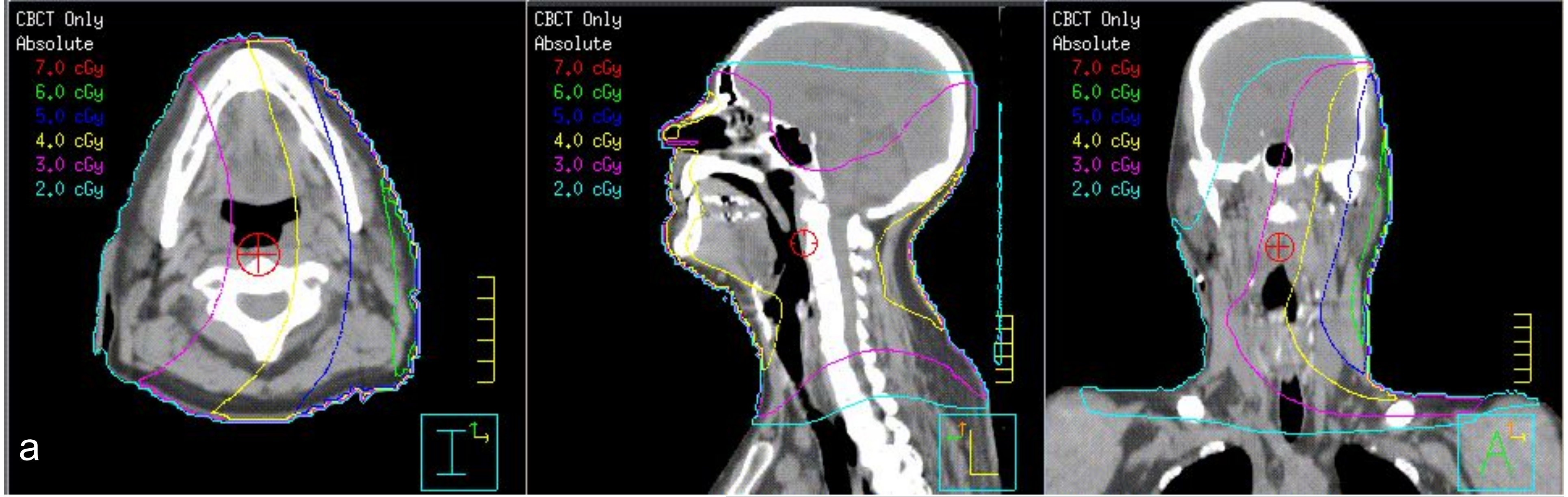


Dose Calculations-Elekta XVI

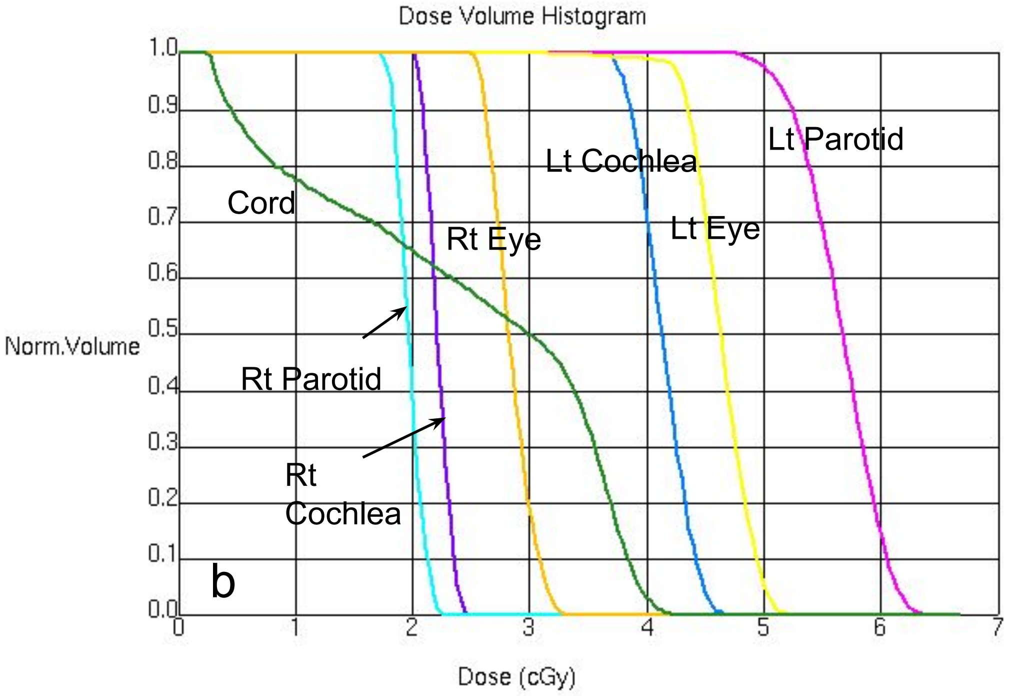


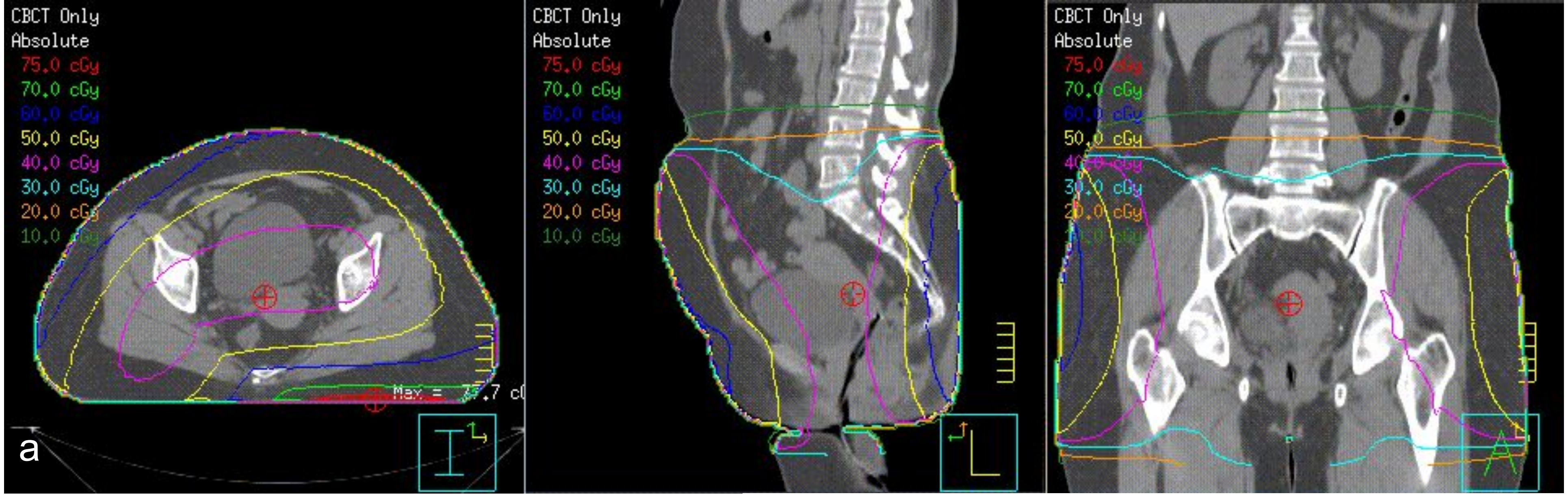


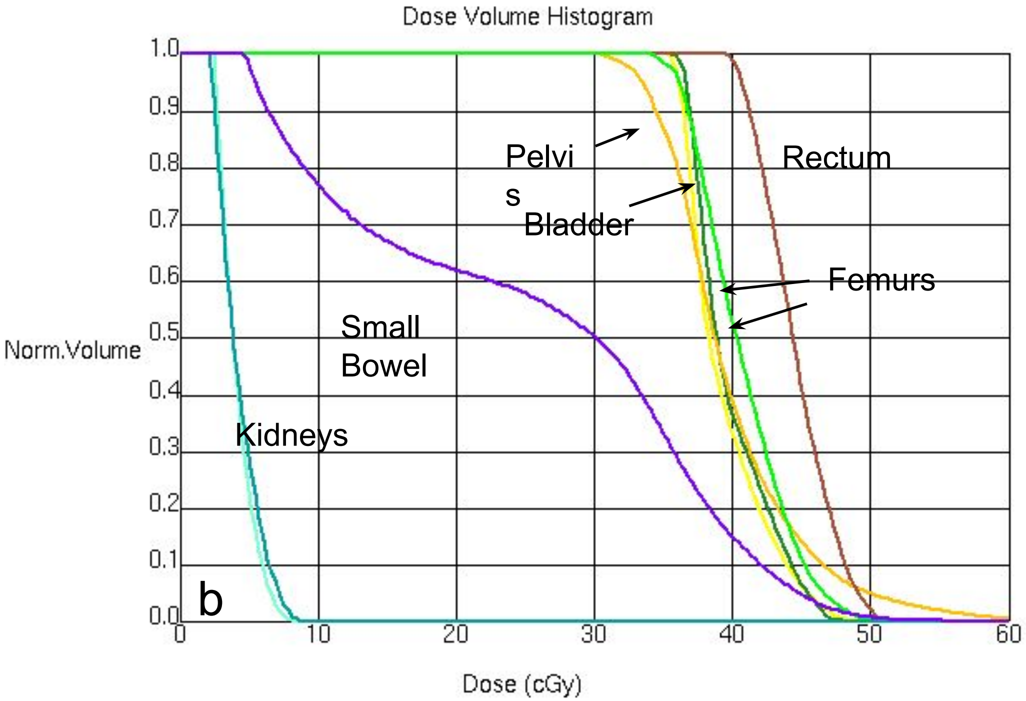




Isodose distribution (a) and dose volume histogram (b) demonstrating imaging dose from 35 fractions of head and neck imaging for one patient.







Isodose distribution (a) and dose volume histogram (b) demonstrating imaging dose from 25 fractions of pelvis imaging for one patient.

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AAPM TG Reports on Imaging Dose

The management of imaging dose during image-guided radiotherapy: Report of the AAPM Task Group 75

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Image guidance doses delivered during radiotherapy: Quantification, management, and reduction: Report of the AAPM Therapy Physics Committee Task Group 180

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AAPM TG Reports on Imaging Dose

TG-75

- Compiles image guidance techniques and their associated dose levels
- Identifies ways to reduce the total imaging dose
- Recommends optimization strategies to trade off imaging dose with improvements in therapeutic dose delivery

TG-180

- Complements TG-75
- Provides an overview on imaging dose from various modalities
- Provides guidelines for commissioning dose calculation methods and managing imaging dose to patients

Effective Dose vs. Absorbed Dose

- The imaging dose referred to in TG-180 is absorbed dose to medium which differs from the effective dose metric used in TG-75.
- Effective dose, as defined by the ICRP, is based on an estimate of biological effect integrated over the entire patient body, requiring a detailed knowledge of the radiation energy spectrum and irradiation geometry, and conversion of absorbed to effective dose, which is not possible with current tools available in radiation therapy.
- Thus, in order to avoid this additional level of complexity, absorbed dose is used in TG-180 rather than effective dose.

TG-75 Recommendations (1)

- In all IGRT treatments, compile a complete picture of all of the imaging procedures to be used before, during, and after treatment

- Identify those image-guidance steps that can potentially be accomplished without the use of ionizing radiation

TG-75 Recommendations (2)

- Configure the image acquisition systems to eliminate dose outside the required field of views (FOVs)

- Plan the imaging technique to be consistent with the image quality and information needed for the treatment decision being made

TG-75 Recommendations (3)

- After arriving at an IGRT imaging scenario that eliminates un-needed dose and optimizes the required exposure, use the resources of this report to estimate the total effective imaging dose, from all sources, that the patient will receive
- Evaluate the total dose patient-by-patient using guidelines for estimating stochastic and deterministic risk, with the understanding that the diagnostic imaging community relies on judgment rather than prescription in assessing individual exposure risk

TG-180 Recommendations (1)

- General Recommendations:
  - Create local imaging protocols with image modality, techniques, and frequency that are suitable for the clinical imaging intent
  - Develop protocols that are specific for pediatric patients
  - Communicate typical imaging doses associated with the imaging procedures used to the radiation oncologists

TG-180 Recommendations (2)

- Imaging dose output and consistency checks:
  - The anticipated imaging dose for each image acquisition procedure with specified protocol parameters should be measured in air or in phantom according to the AAPM dosimetry protocols (i.e. TG-61)
    - If not AAPM protocol, TRS 398 should be used

TG-180 Recommendations (3)

- Imaging dose output and consistency checks:
  - Consistency checks should be performed yearly and after each system upgrade

  - If patient specific image dose verification is desired for a particular patient, in-vivo patient dose measurements should be performed with suitable detectors

TG-180 Recommendations (4)

- Accounting for imaging dose to RT patients:
  - It is recommended that imaging dose be considered as part of the total dose at the treatment planning stage if the dose from repeated imaging procedures is expected to exceed 5% of prescribed therapeutic target dose
  - Why 5%?
    - Clinical relevance, accuracy of dose calculation and delivery, organ dose tolerances, and feasibility in clinical practice

Note on kV Imaging Beam Dosimetry

- kV imaging beam cannot be calculated using TPS
- If that becomes possible, it requires:
  - Beam data collection (PDDs, profiles, output factors)
    - Difficulties include low dose rate and dependence on the phantom media
    - Possible to use MC data validated by measurements
  - Beam modeling/commissioning

Dose from Different Imaging Devices/Techniques

- 2D imaging
  - MV portal imaging
  - kV digital radiography
  - Room-mounted kV imaging
- 3D imaging
  - Cone Beam CT
    - MV CBCT
    - kV CBCT
    - MV CT

} • Imaging dose < 5% threshold, unless there are a large number of images; no need to account for

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

Accounting for Imaging Dose

- TG-180 recommends two methods to estimate imaging dose:
  - Patient specific
  - Non-patient specific

Accounting for Imaging Dose

- Patient specific calculations:
  - Straightforward for megavoltage imaging using TPS
  - Only possible using Monte Carlo for kilovoltage imaging
  - Provides accurate organ dose calculations from image procedures

Accounting for Imaging Dose

- Non-patient specific estimations:
  - Dependence of imaging dose on patient anatomy is small in most cases, hence dose estimates could be provided in the form of organ dose “look-up” tables (provided in TG-180)
  - Requires knowledge of imaging protocol used
  - The table values can be scaled with mAs used for imaging

Accounting for Imaging Dose

- Non-patient specific estimations:
  - Simple and provides clinicians with adequate estimates of imaging dose to organs
  - It is an estimate and is applicable for small magnitude of imaging dose
  - It dose not provide dose distributions

kV CBCT Imaging Dose Look-up Tables

Standard Head, Head & Neck		
Organ	D50 Range (cGy)	D10 Range (cGy)
Brain	0.15-0.22	0.16-0.23
Larynx	0.21-00.29	0.25-0.33
Oral Cavity	0.13-0.26	0.20-0.31
Parotids	0.26-0.42	0.31-0.48
Spinal Cord	0.16-0.25	0.19-0.32
Thyroid	0.07-0.23	0.11-0.32
Esophagus	0.07-0.16	0.14-0.26
Skin	0.18-0.27	0.34-0.44
Bones	0.25-0.65	0.64-1.07

Organ doses for the head & neck and brain treatment sites from Varian OBI v1.4 using Standard Head kV-CBCT scan (Full fan,100 kVp, 145 mAs, 200^o rotation). D50 and D10 are minimum dose delivered to 50% and 10% of the organ volume respectively.

kV CBCT Imaging Dose Look-up Tables

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

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.

kV CBCT Imaging Dose Look-up Tables

Organ doses for the chest treatment site from Varian OBI v1.4 using Low-dose Thorax kV-CBCT scan (Half fan,110 kVp, 262 mAs, 360º rotation).

Low-dose Thorax		
Organ	D50 Range (cGy)	D10 Range (cGy)
Aorta	0.42-0.58	0.44-0.63
Lungs	0.30-0.61	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	0.32-0.57	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

kV CBCT Imaging Dose Look-up Tables

Pelvis Scan, Prostate Isocenter		
Organ	D50 Range (cGy)	D10 Range (cGy)
Bladder	1.36-2.20	1.72-2.69
Bowel	1.54-1.91	2.04-2.65
Femoral Heads	2.40-3.60	3.22-4.88
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
Bone	2.93-3.96	4.61-5.72

Organ doses for the pelvis treatment site from Varian OBI v1.4 using Pelvis kV-CBCT scan (Half fan, 125 kVp, 700 mAs, 360^{o} rotation).

kV CBCT Imaging Dose Look-up Tables

Pelvis	
Organ	D50 Range (cGy)
Bladder	1.1-2.5
Rectum	1.3-2.4
Small Bowel	1.1-2.3

With Bowtie

Pelvis	
Organ	D50 Range (cGy)
Bladder	0.9-2.0
Rectum	1.1-1.9
Small Bowel	1.0-1.8

W/O Bowtie

Organ doses for the pelvis treatment site from Elekta XVI kV-CBCT scan using M cassette (120 kVp, 650 mAs, 360^{o} rotation).

kV CBCT Imaging Dose Look-up Tables

Pelvis	
Organ	D50 Range (cGy)
Bladder	1.1-2.5
Rectum	1.3-2.4
Small Bowel	1.1-2.3

With Bowtie

To use the table, the dose values need to be scaled based on the kVp and total mAs of the imaging protocol used

Organ doses for the pelvis treatment site from Elekta XVI kV-CBCT scan using M cassette (120 kVp, 650 mAs, 360^{o} rotation).

Imaging Dose Reduction Techniques (1)

– Reduce the imaging field cranio-caudally

– Reduce the size of MV portal images

– Choose the appropriate MVCT pitch in TomoTherapy

– Choose lower MU setting for MV-CBCT, restrict the imaging field of view (FOV), use bony anatomy for set up

Imaging Dose Reduction Techniques (2)

– Consider the type of imaging needed (2D vs. 3D), use ALARA as the guiding principle, consider 2D if two planar kV radiographs are sufficient

– Optimize imaging parameters (e.g. kVp, mAs), select appropriate default clinical protocols, and use lower dose protocols for pediatric cases

Imaging Dose Reduction Techniques (3)

– Use partial rotation kV CBCT protocols to avoid critical organs

– Optimize beam entry/exit direction to reduce organ dose

– Use beam filters when acquiring planar kV images

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Summary and Conclusions

- Accounting for the megavoltage imaging dose in treatment plans is often possible, but may require beam data collection and modeling
- Accounting for kilovoltage imaging dose in treatment plans is not possible

Summary and Conclusions

- Two AAPM reports (TG-75 and 180) address the issue of imaging dose, its magnitude, dose reduction, and accounting for it

- Accounting for imaging dose often involves estimating it based on look-up tables

Questions?