DOSES FROM IMAGE GUIDANCE DURING RADIATION THERAPY

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Disclosures

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

Outline

- Introduction
- Magnitude of Imaging dose
- Inhomogeneity of Imaging Dose
- Peripheral Dose from Imaging
- Imaging Dose Reduction/Optimization
- Summary and Conclusions

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Introduction

- Imaging dose had traditionally been deemed insignificant
  - -Weekly imaging (film-based/EPID)
  - -Low magnitude as compared to therapeutic dose
- Volumetric daily imaging results in higher doses, hence increased attention to the imaging dose

Is Imaging Dose of Concern?

- Perhaps, but for the most part the magnitude of imaging dose is negligible, specially comparing to the therapeutic dose

- This may become significant if frequency of imaging is high, MV imaging is used, and for pediatric cases

- Since the imaged volume is almost always larger than treated volume, more of the healthy tissue, normally not irradiated as part of radiation therapy, is exposed to imaging dose

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Magnitude of Imaging Dose

- Imaging dose magnitude is dependent on beam quality, image acquisition parameters, frequency of imaging, equipment, modality, …

Factors Affecting Imaging Dose (1)

- Beam quality (kV vs. MV)
- Frequency of imaging
- Planar vs. volumetric imaging
- Patient size (more important for kV imaging)

Factors Affecting Imaging Dose (2)

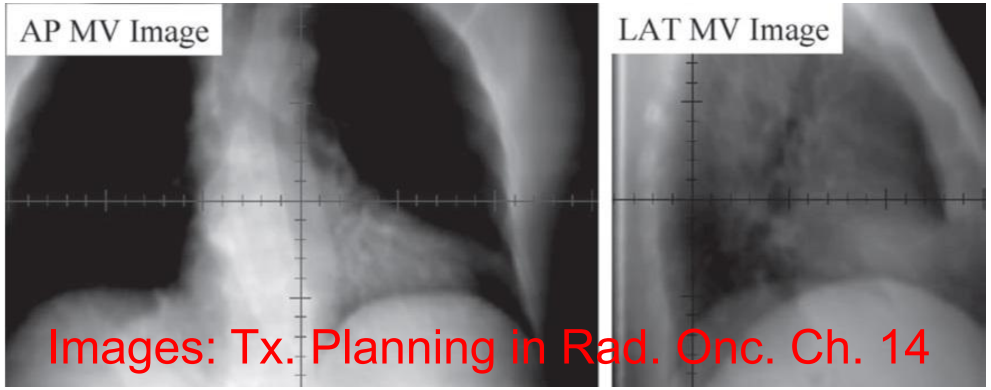
- Number of MUs delivered for MV imaging
- Technique (mAs and kVp) and filtration used for kV imaging
- The pitch used for helical kV and MV CT imaging
- Imaging field size, length of the imaged volume, arc start/stop angles (CBCT)

Imaging Dose from Different Modalities

MV Portal Imaging

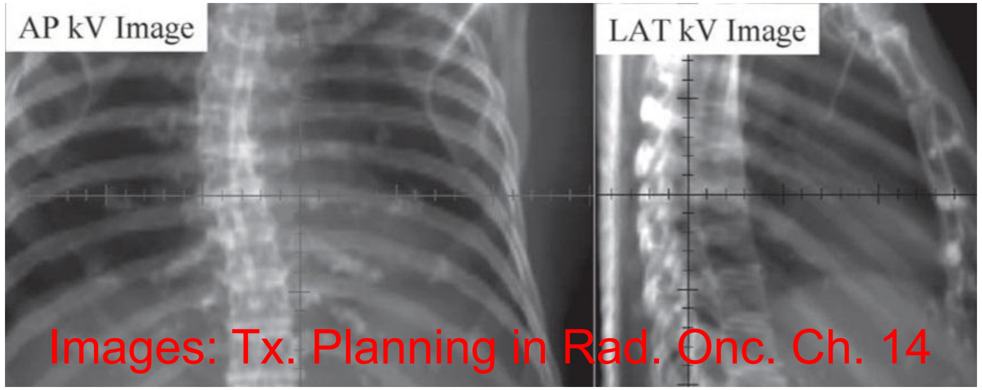
- Imaging doses from EPIDs generally estimated to be ~ 2 MU per portal image using 6 MV beam (more for double exposure)

- Using 2.5 MV beam (Varian TrueBeam) reduces this dose by half



kV Digital Radiography

- Imaging dose from kV digital radiography (portal imaging) is substantially less than MV portal imaging (A fraction of cGy for an orthogonal pair)
- The dose to bone, however, is 2-3 times that of soft tissue
- In addition, dose drop-off is rapid and exit dose is substantially less than that from MV portal imaging



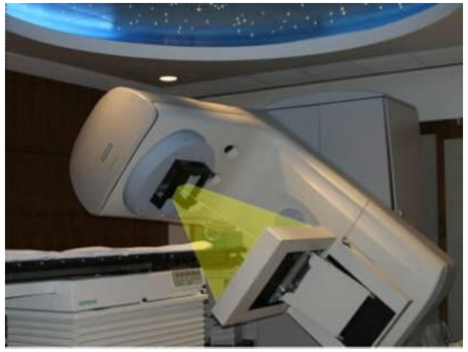
Images: Tx. Planning in Rad. Onc. Ch. 14

Room-Mounted 2D Imaging

- Exclusively use kV beams for stereoscopic positioning with large source-to-patient/imager distance, imaging done prior to and during treatment
- Dose per image is in mGy range, but due to frequent imaging cumulative dose/fraction is in cGy range
- Primary use: SRS/SBRT (1-5 fractions)

Megavoltage CBCT

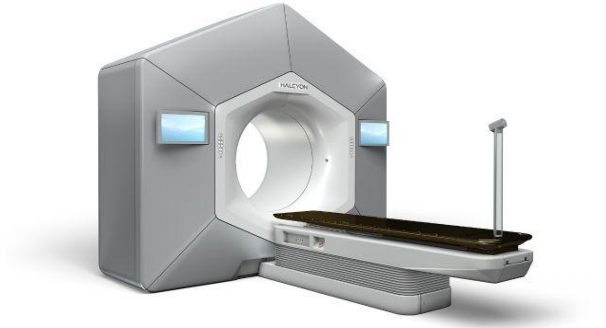
- Siemens 6 MV CBCT:1-12 cGy depending on MU setting



- Varian Halcyon 6 MV FFF beam*

  ~7-8 cGy for high quality mode (10 MU)

  Reduced by half for low dose mode (5 MU)



*<u>Halcyon now utilizes kV CBCT</u>

Megavoltage CT-TomoTherapy/Radixact

- Estimated to be 1-4 cGy depending on pitch
  - Fine pitch: 4mm couch travel/rotation
  - Normal pitch: 8mm couch travel/rotation
  - Coarse pitch: 12mm couch travel/rotation

- Scan length affects the total dose delivered to patient

Kilovoltage CT-Radixact

- Ranges from <1 to 4 cGy
- Dose varies depending on protocol used and scan length but is comparable to kV CBCT

Anthropomorphic phantom imaging dose Pelvis

Modality	Anatomy	Body Size	Mode	FOV (mm)	Dose (cGy)
ClearRT	Pelvis	X-Large	Fine	440	3.6
		X-Large	Normal	440	2.8
	Thorax	X-Large	Fine	440	2.4
		X-Large	Normal	440	1.9
CBCT	Pelvis	Default Settings			2.4
	Pelvis Large				5.2
	Thorax				0.7
CT	Onco-Body	Default settings (120 kVp)			1.6

Measurements based on 18 cm-long scans

Kilovoltage CBCT

- Depends heavily on the protocol used (mAs, kVp)
- Head and neck protocols (Typically 100 kVp, 0.1-0.4 mAs/acquisition, partial arc): <u>Less than 1 cGy</u>
- Thorax protocols (Typically 110-120 kVp, 0.3-0.4 mAs/acquisition, full arc): <u>0.5-3 cGy</u>
- Pelvis protocols (Typically 120 kVp, 1.2-2.0 mAs/acquisition): <u>1-4 cGy</u>

Magnitude of Imaging Dose-Summary

- MV portal imaging: ~3-4 cGy/image pair
  - Lower if 2.5 MV imaging used
- kV digital radiography: << 1 cGY/image pair
- Room-mounted kV imaging: << 1 cGy/image pair
- MV CBCT: 1-12 cGy/scan
- MV CT: 1-4 cGy/scan
- kV CBCT: 0.1-4 cGy/scan
- kV CT: 1-4 cGy (18 cm long scan)

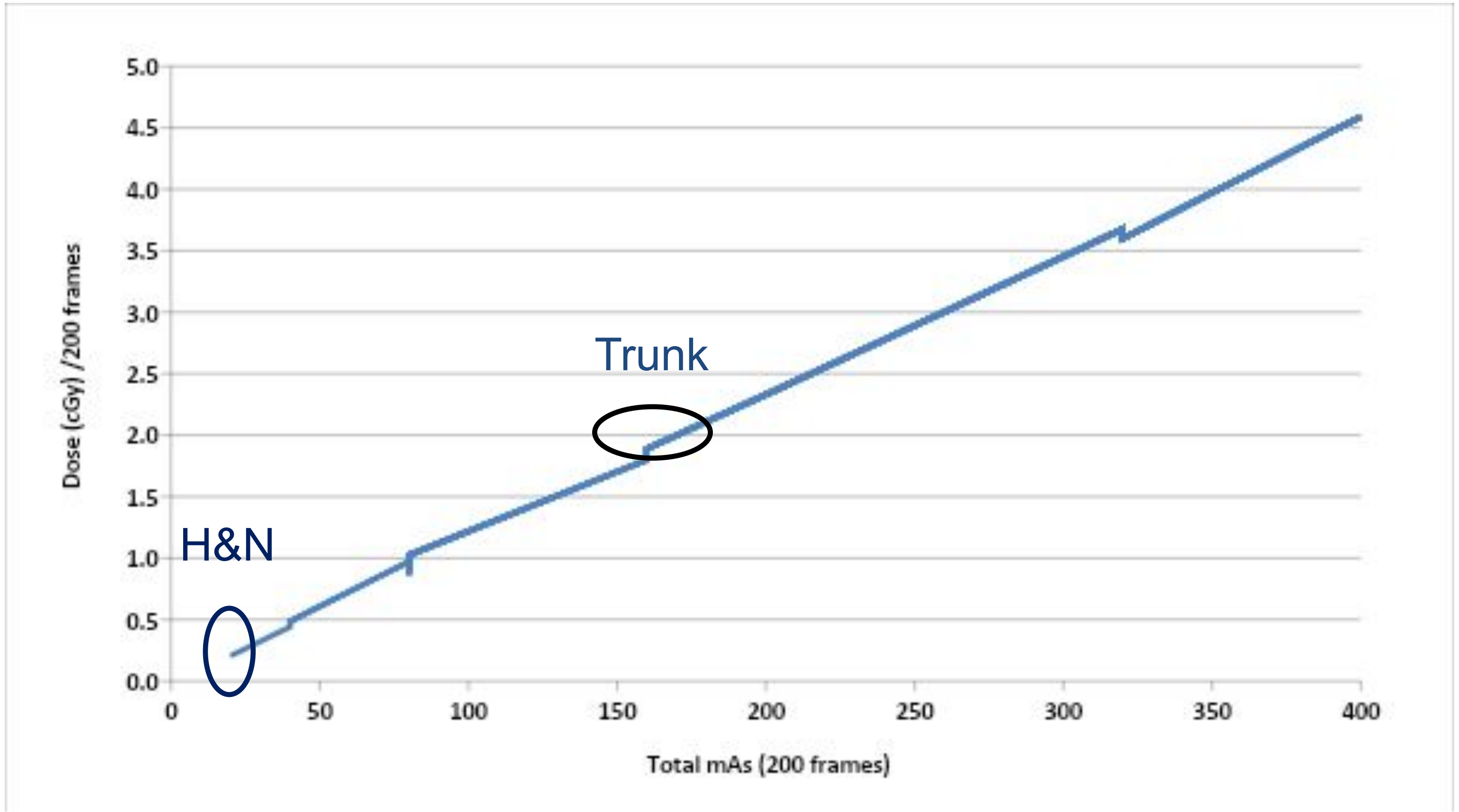
*These are estimates only and actual dose depends on many factors including patient size

Focusing on kV CBCT

Imaging Dose in kV CBCT

- Tube current -- Higher mA higher dose (linear)
- Applied voltage -- Higher kVp higher dose (~kVp^2)
- Filtration -- Addition of bowtie lower dose
- Arc start/stop angle -- Affects imaged volume/OAR dose
- Blade setting/cassette size -- Affects imaged volume
- Patient size -- Smaller patient higher organ dose

Effect of Tube Current



Variation of imaging dose with mAs. The dose was measured at 1 cm depth using an XVI unit, delivering 200 imaging frames in stationary position, keeping kVp constant.

Effect of Applied Voltage

- Increasing applied voltage from 100-120 kVp, keeping mAs constant, results in ~60% dose increase
  (Based on measurements)

- The amount of radiation produced increases as the square of the kilovoltage: Intensity is proportional to $(kVp)^2$
  (Christensen's Physics of Diagnostic Radiology)

Dose Variation with Protocol (Elekta XVI)

- Fast Head and Neck:
  100 kVp 18.3 mAs 200º Rotation Full-Fan F0 0.11 cGy*
- S20 Head and Neck:
  100 kVp 36.6 mAs 200º Rotation Full-Fan F0 0.16 cGy
- Chest M20:
  120 kVp 264 mAs 360º Rotation Partial-Fan F1 1.27 cGy
- M20 Pelvis Abdomen:
  120 kVp 1056 mAs 360º Rotation Partial-Fan F0 5.42 cGy
- M10 Prostate Chest:
  120 kVp 1056 mAs 360º Rotation Partial-Fan F0 7.22 cGy
- M20 Pelvis high mAs:
  120 kVp 1056 mAs 360º Rotation Partial-Fan F0 7.33 cGy
- Prostate M10:
  120 kVp 1689.6 mAs 360º Rotation Partial-Fan F1 8.34 cGy

*Dose measured in air at isocenter for a single acquisition

76 fold increase

Dose Variation with Protocol (Varian TrueBeam)

Protocol	kVp	mAs	Rotation	Bowtie	Dose
Image Gently:	80 kVp	100 mAs	200º Rotation	Full-Fan Bowtie	0.21 cGy*
Head:	100 kVp	150 mAs	200º Rotation	Full-Fan Bowtie	0.58 cGy
Thorax:	125 kVp	270 mAs	360º Rotation	Half-Fan Bowtie	1.90 cGy
Spotlight:	125 kVp	750 mAs	200º Rotation	Full-Fan Bowtie	4.80 cGy
Pelvis:	125 kVp	1080 mAs	360º Rotation	Half-Fan Bowtie	6.86 cGy
Pelvis Obese:	140 kVp	1687.5 mAs	360º Rotation	Half-Fan Bowtie	14.09 cGy

*Dose measured in air at isocenter for a single acquisition

67 fold increase

Effect of Filtration

- Bowtie filter

Addition of bowtie filter reduces imaging dose, providing the mAs is kept the same

- Inherent filtration

Some newer kV tubes have added filtration reducing imaging dose

Effect of Arc Length and Field Size

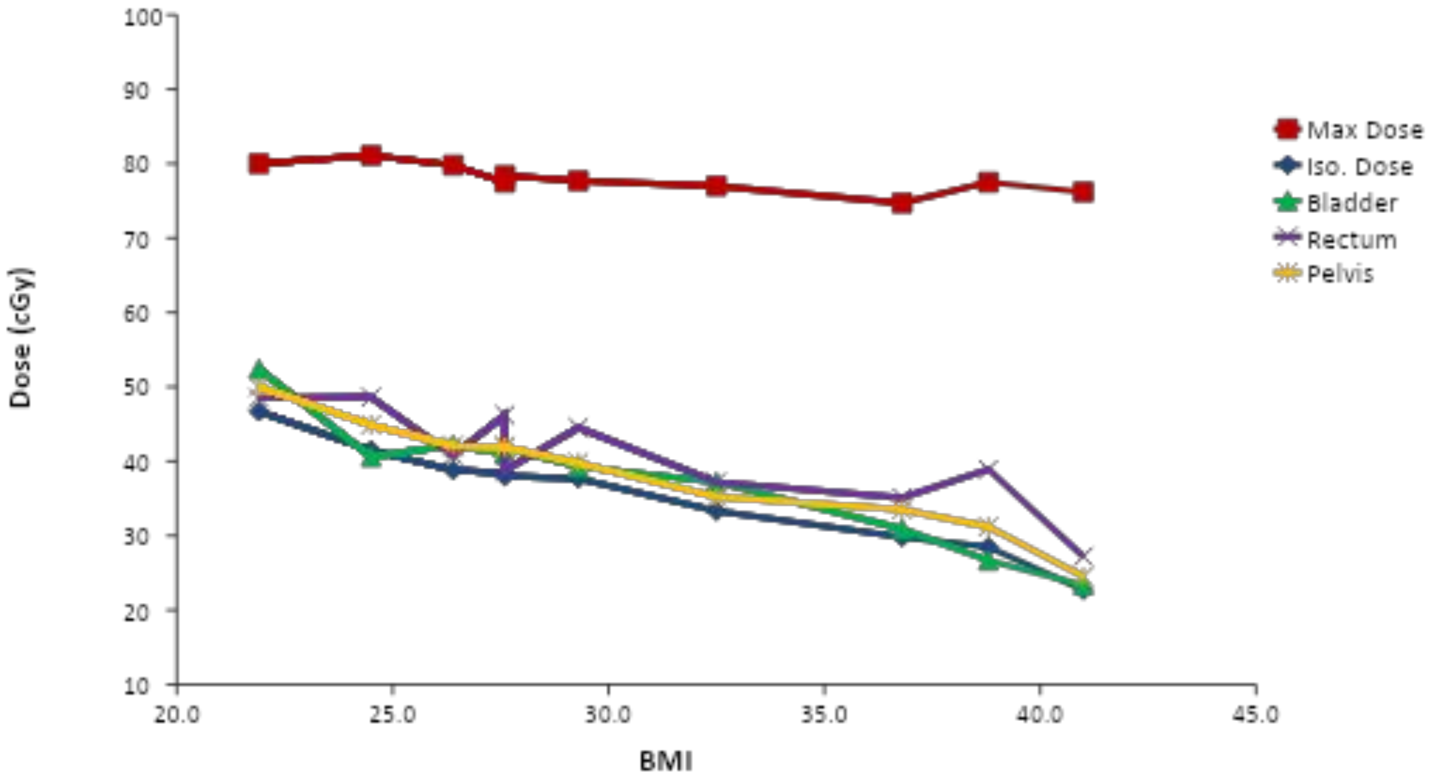
- Arc start/stop angle

Affects the dose distribution within the imaged volume, may affect dose to OARs

- Blade settings/cassette size

Smaller blade settings or cassette size reduces the imaged volume cranio-caudally

Effect of Patient Size



Correlation of imaging dose with body mass index for 25 fractions of pelvis kV CBCT imaging for 10 patients. Organ doses are mean dose values. The dose to pelvic bones is underestimated by a factor of 2–3 due to the inability of planning system to compute the dose accurately in bone.

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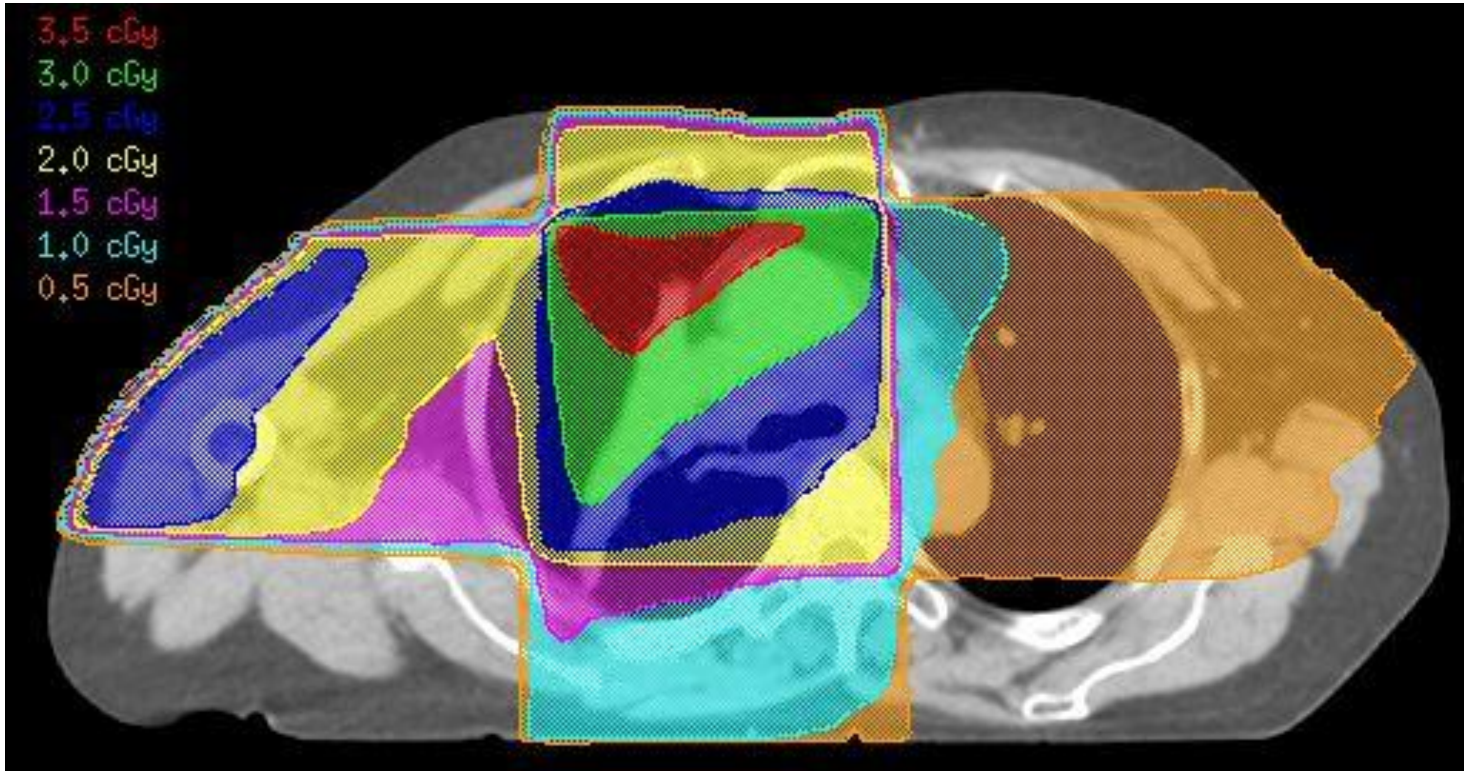
Inhomogeneity of Imaging Dose

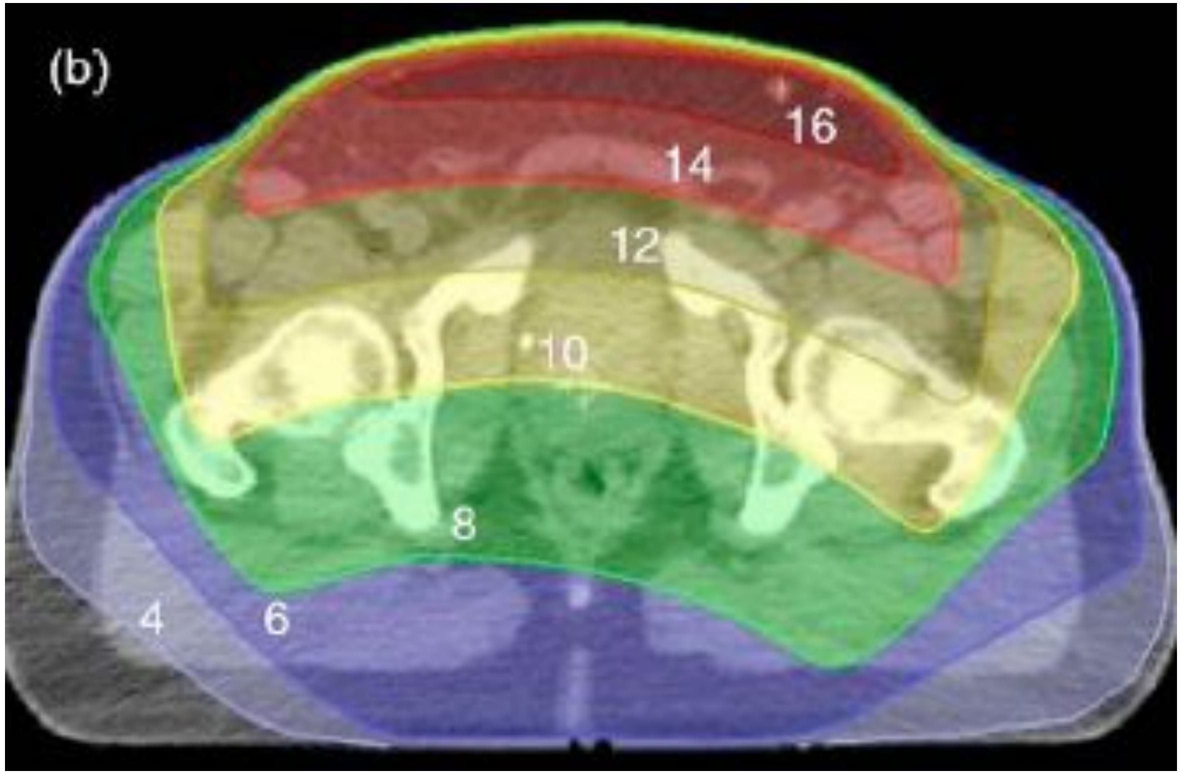
- Megavoltage portal imaging produces a semi-homogeneous dose distribution within the images volume
- Megavoltage CBCT produces a non-homogenous dose distribution due to gantry rotation angles
- Kilovoltage radiography exhibits rapid drop-off of dose with depth and causes increased dose to bone
- Kilovoltage CBCT produces a non-homogeneous dose distribution due to gantry rotation angles and increased dose to bone

Megavoltage Portal Imaging



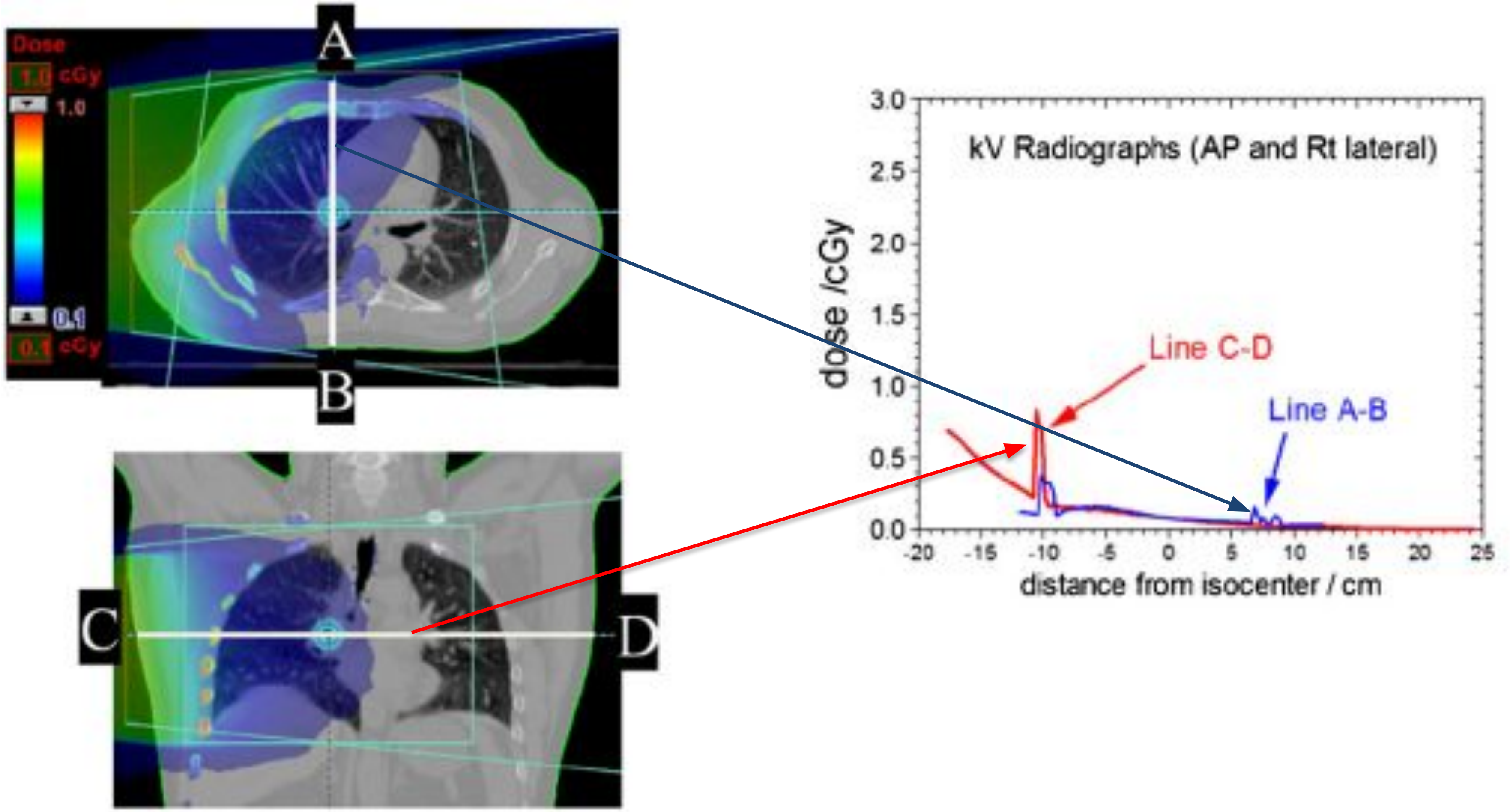
Distribution of dose deposited in the chest by a pair of 6 MV portal images. (2 MU each image)

Megavoltage CT



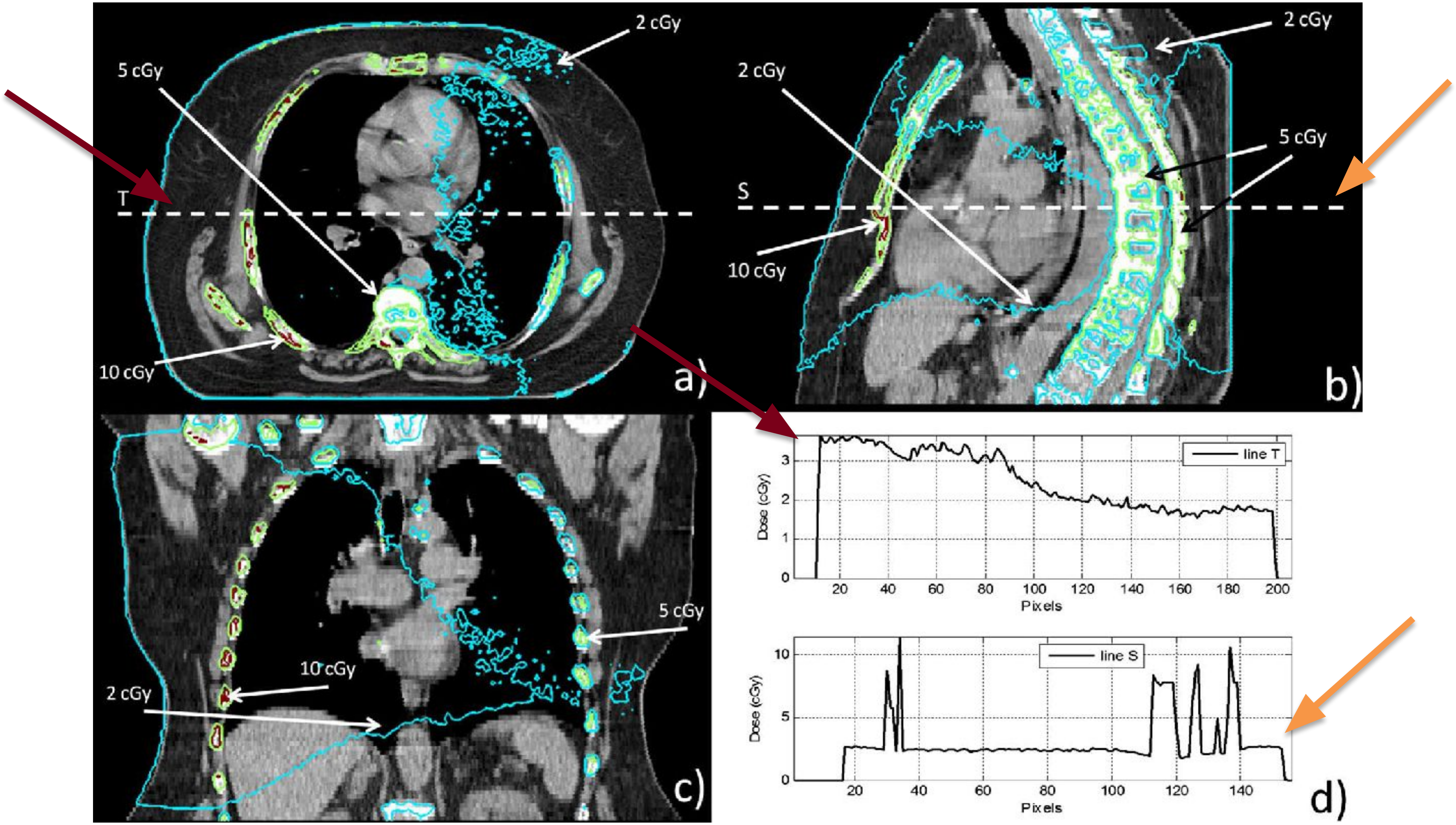
Distribution of dose deposited in the pelvis by a single fraction of MV CBCT imaging for a prostate patient, with 10 cGy at isocenter. The isodose lines are labeled in cGy.

Kilovoltage Radiography



Distribution of dose deposited in the lung by a pair of orthogonal kV radiographs. Absolute dose profiles show enhanced bone dose.

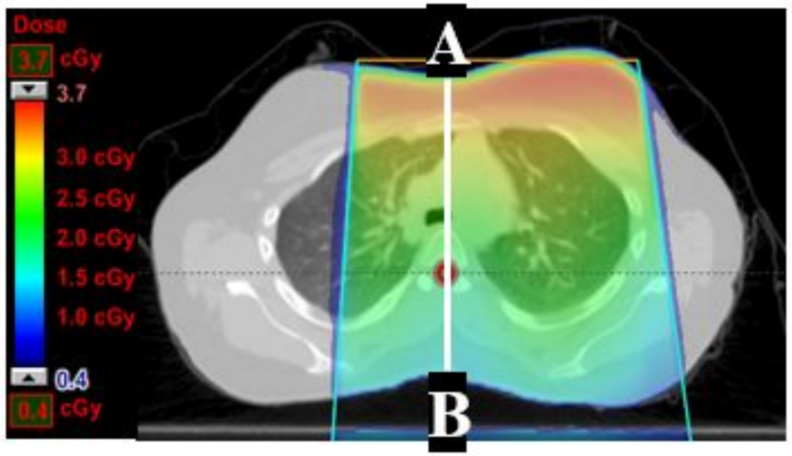
Kilovoltage CBCT



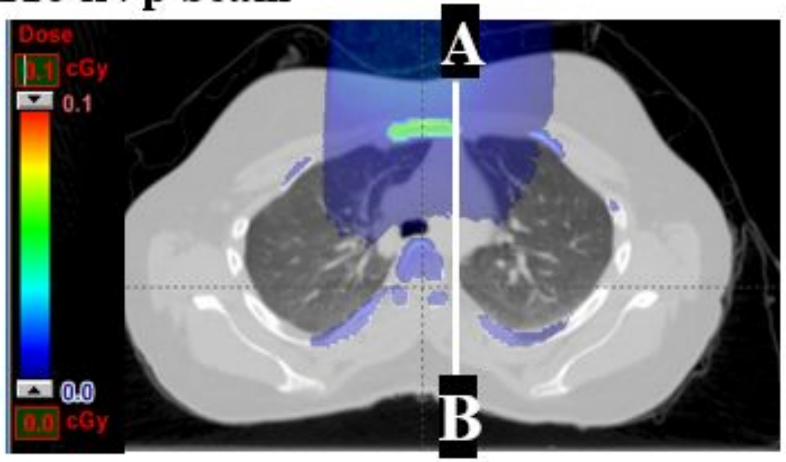
Distribution of dose in the lung from XVI CBCT lung scan simulated using the M20 cassette and F1 filter. Absolute dose profiles show enhanced bone dose.

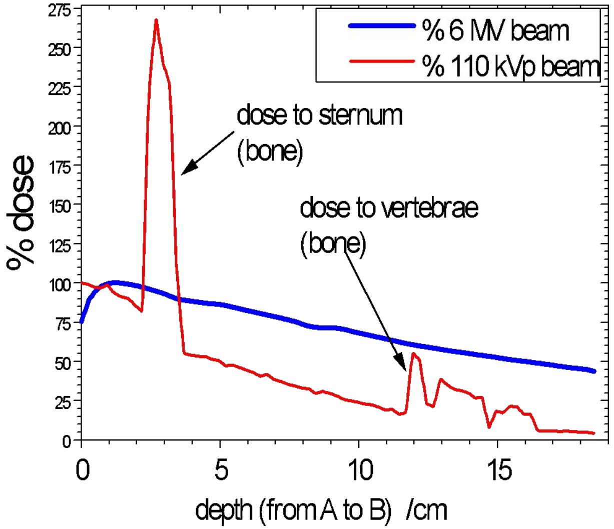
Dose Inhomogeneity Within the Body (kV vs. MV)

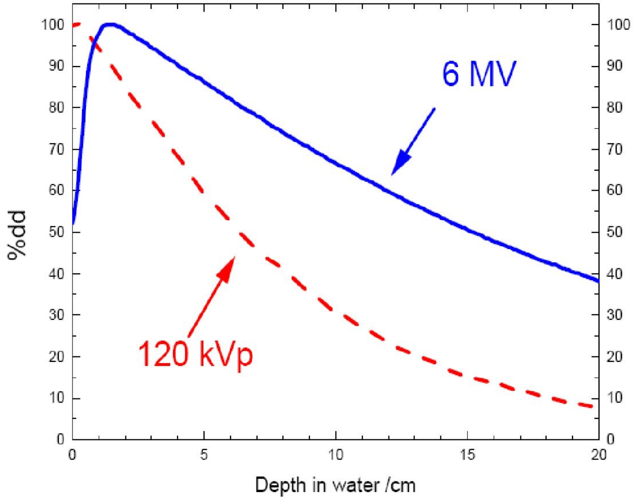
6 MV beam



110 kVp beam







6 MV vs. 120 kVp PDD curve

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Peripheral Dose from Imaging

- Peripheral dose: Dose outside the treated volume

- Sources: Scattered and leakage as well as imaging dose
  - It is of interest when an OAR or an implanted electronic device is near the treated volume

AAPM TG 158: Measurement and calculation of doses outside the treated volume from external-beam radiation therapy

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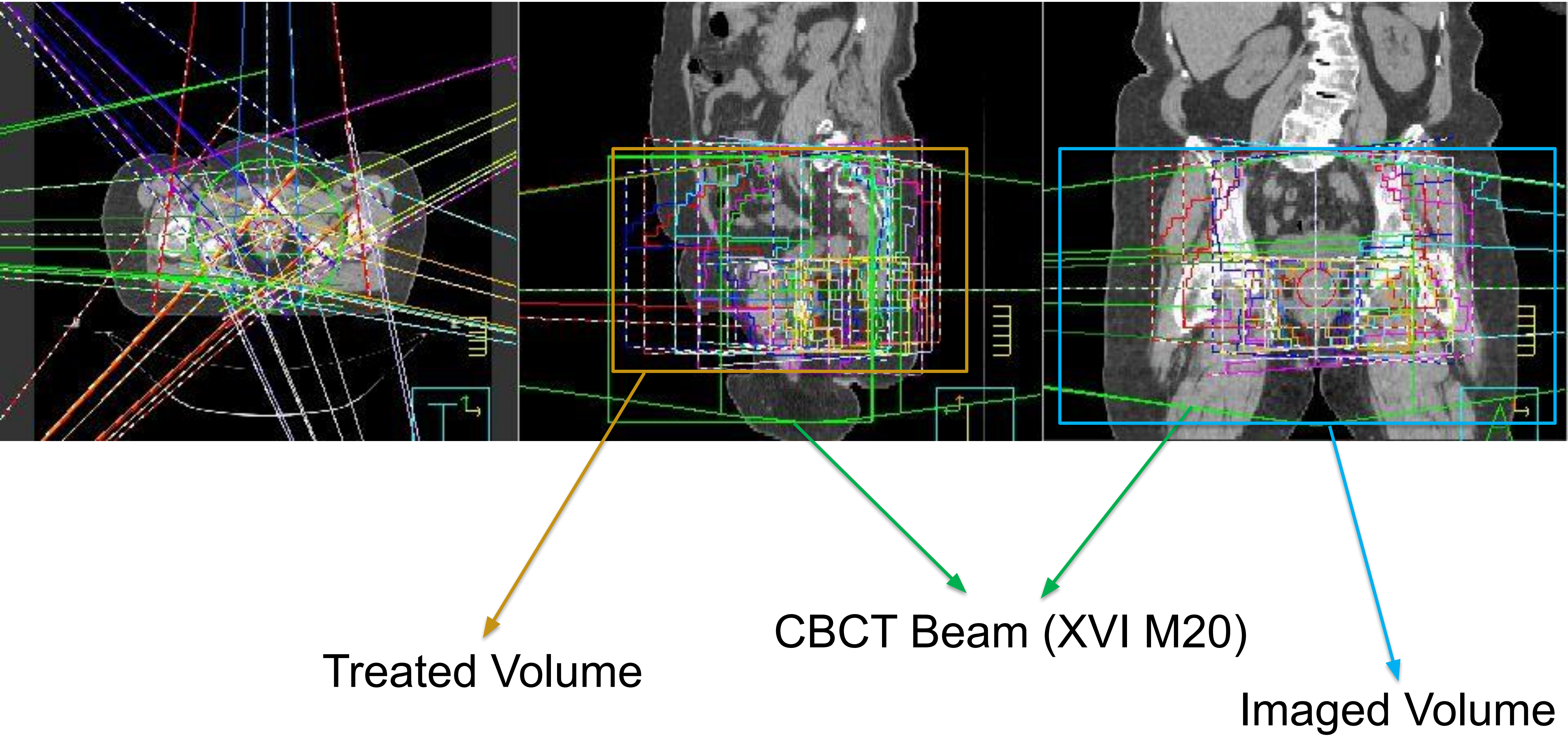
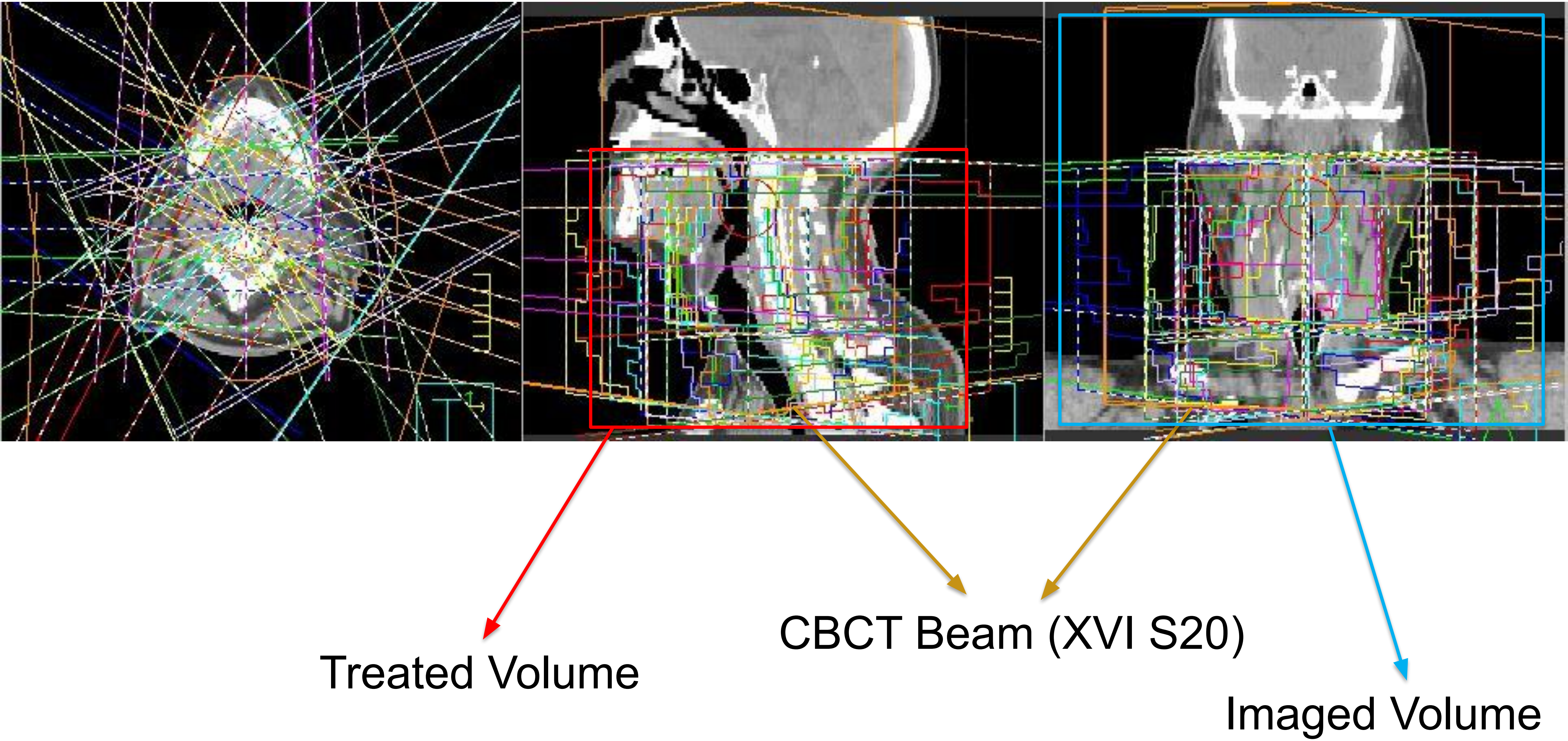
TABLE III. Nominal radiation dose ranges to patients from representative standard clinical concomitant imaging procedures. Note that actual values will depend heavily upon protocol and mode selection as well as patient size and image quality requirements.[173,174,179–183]

Imaging method	Parameter assumptions or body area	Estimated radiation dose per image (cGy)
Portal imaging (MV)	Solid-state flat-panel detectors; 100 cm source/isocenter distance	< 1–5
Planar imaging (kV)	Gantry-mounted kV system or ceiling/floor-mounted kV sources/flat-panel detectors	~0.02–0.3
Cone-beam computed tomography (kV) (Elekta XVI®, Varian OBI®)	Imaging site and doses to structures:	
	Head/neck	
	Soft tissue	~0.2–2
	Red bone marrow	~4–5
	Bone surfaces	~9–20
	Chest	
	Soft tissue	~0.5–3.5
	Red bone marrow	~1–4
	Bone surfaces	~2–10
	Pelvis	
	Soft tissue	~0.5–5
	Red bone marrow	~2–3
	Bone surfaces	~5–8


Treated Volume
CBCT Beam (XVI M20)
Imaged Volume


Treated Volume
CBCT Beam (XVI S20)
Imaged Volume

Magnitude of Peripheral Dose from Imaging

- Dose from **kV CBCT** is of the same order of magnitude as that from IMRT:
  - ≥ 1 cGy outside the imaged volume, reduced to 0.25 cGy at 25 cm from CA (measured in Rando) (Perks et al. 2008)

- Dose from **kV CBCT** is of the same order of magnitude as that from linac leakage:
  - ~15 cGy at the field border to ~0.5 cGy 30 cm from treatment field (for 25 fractions, MC simulated) (Qiu et al. 2012)

Magnitude of Peripheral Dose from Imaging

- Dose from **MV CBCT** of the same order of magnitude as that from kV CBCT:
  - ~.01-0.3 cGy/MU 15 cm from field edge (measured in phantom) (Jia et al. 2012)

- Dose from **kV CT** (Radixact) higher than CBCT (Ehler and Alaei 2022)

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Imaging Dose Reduction

- May be warranted in order to:
  - Reduce dose burden of organs at risk
  - Reduce dose to pediatric patients
  - Limit dose to electronic devices
  - …

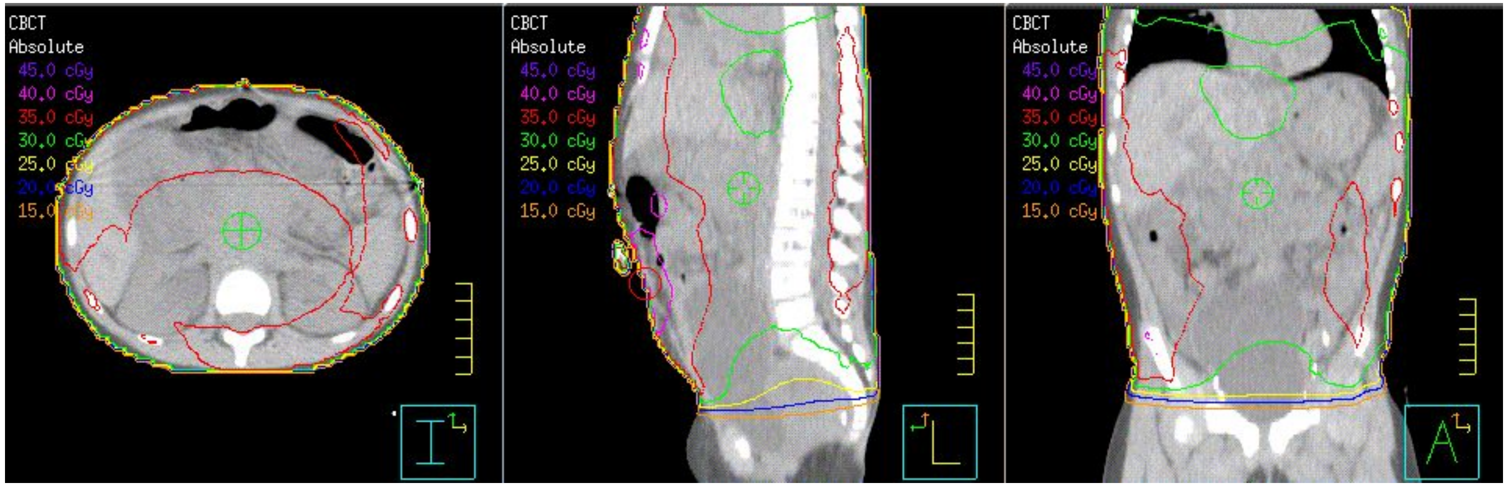
Methods for Reducing Imaging Dose (General)

- Limiting collimator size in double-exposure portal imaging
- Using lower MU settings in MV CBCT
- Scanning in coarse mode in MV CT
- Using kV instead of MV imaging

Methods for Reducing Imaging Dose (kV Imaging)

- Using lower dose protocol (lower mAs, kVp)
- Reducing the scan length cranio-caudally
- Reducing the number of projections
- Reducing/adjusting the gantry rotation angles
- Using filters

Using Lower Dose Protocol



M20 Pelvis/Abdomen protocol (120 kVp, 1 mAs)

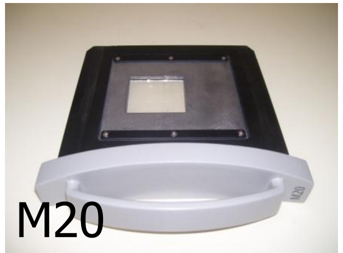
S20 H&N protocol (100 kVp, 0.1 mAs)

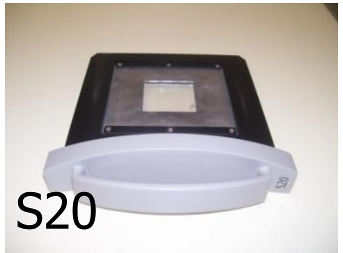
Dose reduced 18 fold

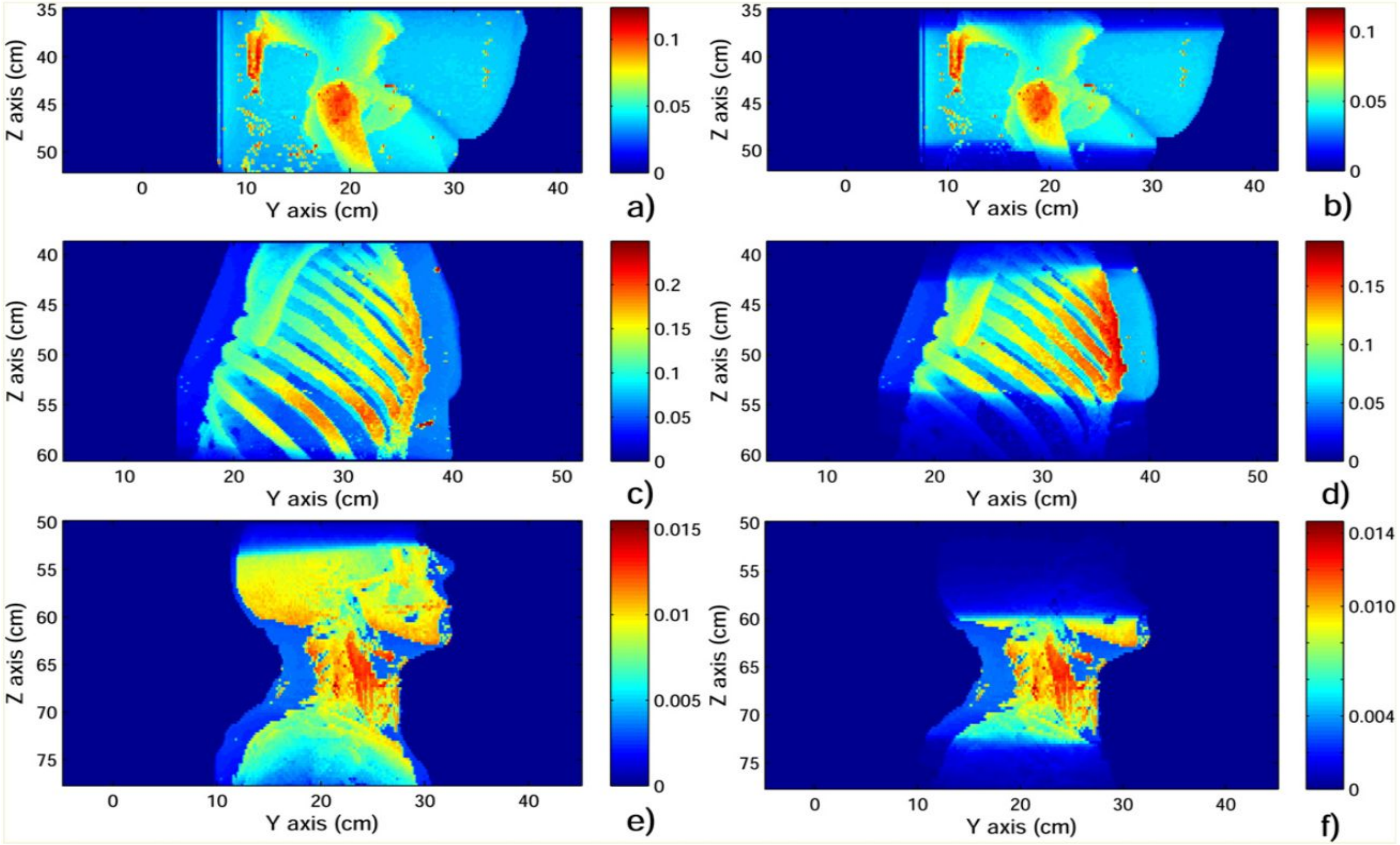
Eleven imaging sessions
Pediatric patient

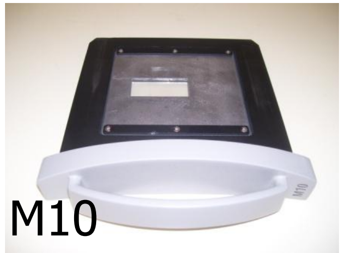
Alaei et al., AAPM 2013 Annual Meeting

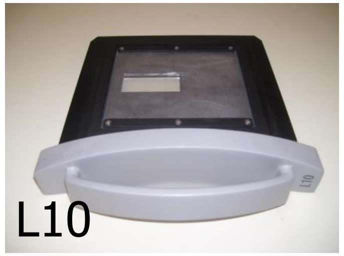
Reducing the Scan Length

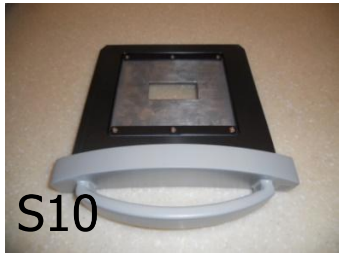






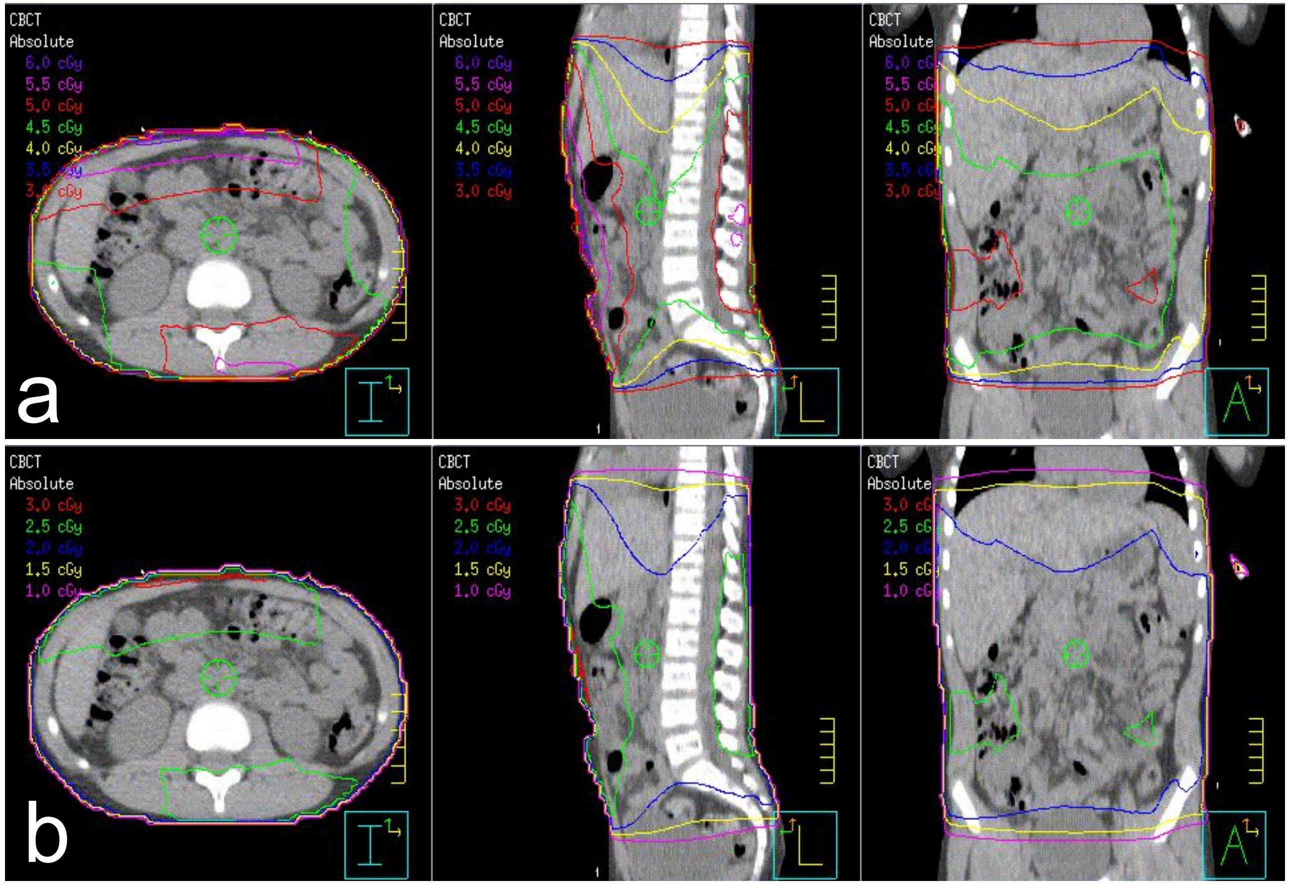






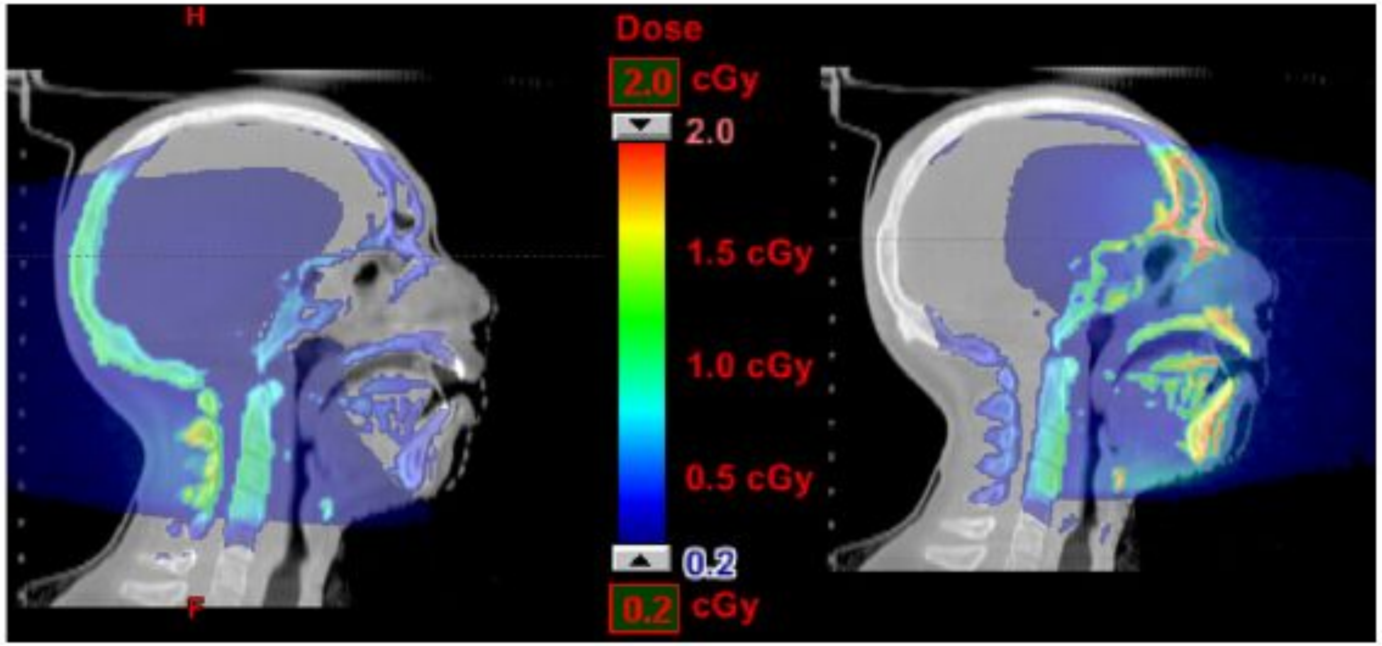
Dose accumulated in color-wash on the sagittal plane for (a, b) pelvis, (c, d) chest, and (e, f) head and neck (a, c, e) for single CBCT scan. Patient dose (in Gy) using S20, M20, and L20 cassettes. (b, d, f) Patient dose using S10, M10, and L10 cassettes. All doses shown are for F0 filter.

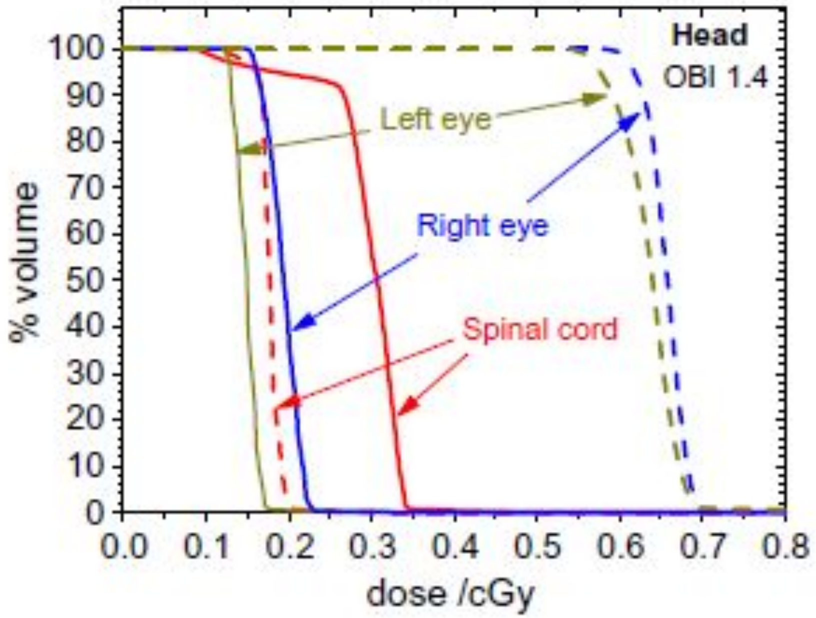
Reducing the Number of Projections



The dose distribution from one daily CBCT imaging using a) the standard protocol used for pelvic imaging and b) the same protocol but reducing the number of frames by half demonstrating a 50% reduction in dose.

Reducing/Adjusting Gantry Rotation Angles





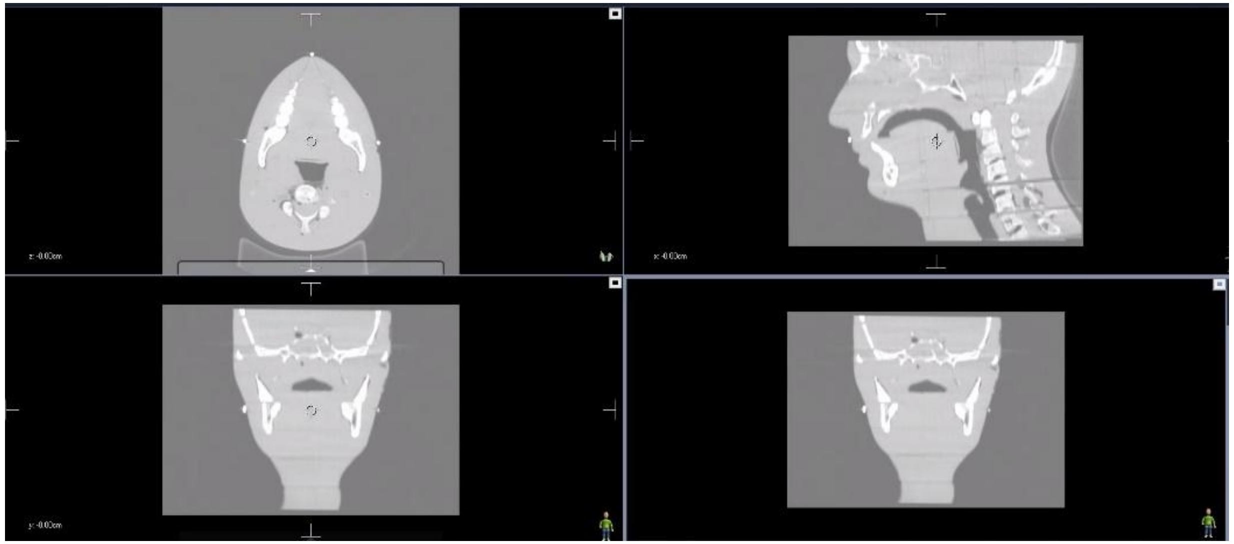
The difference in organ doses when the x-ray source is rotated "below" (solid line) and "above" (dashed line) the patient.

Is Reducing Imaging Dose Always a Good Practice?

- Reducing imaging dose is good practice if it does not adversely affect the quality of the image, and/or lead to repeat imaging
  - Image quality for the reduced dose protocol must be adequate for patient positioning and/or tumor/OAR visualization
- Perhaps imaging dose optimization is a better term to use than imaging dose reduction

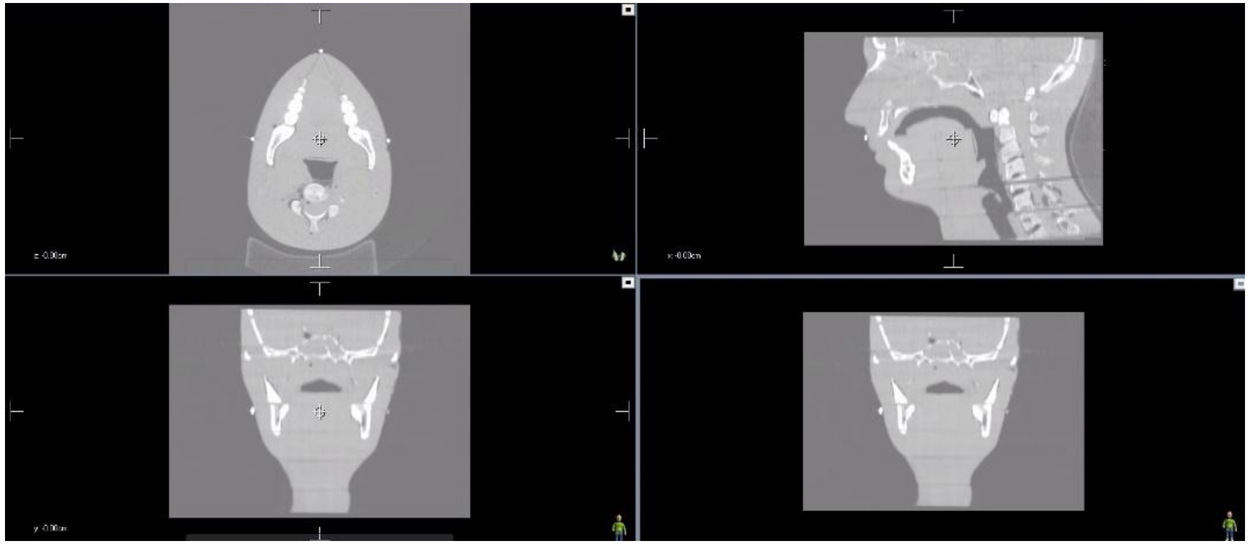
CBCT Imaging Dose Optimization

Standard Head Protocol, Varian TrueBeam



Auto shifts on TrueBeam:
Vert 0.13 Rtn 0
Long -.15 Pitch 0.3
Lat -0.06 Roll -0.3

Number of frames reduced by ~2

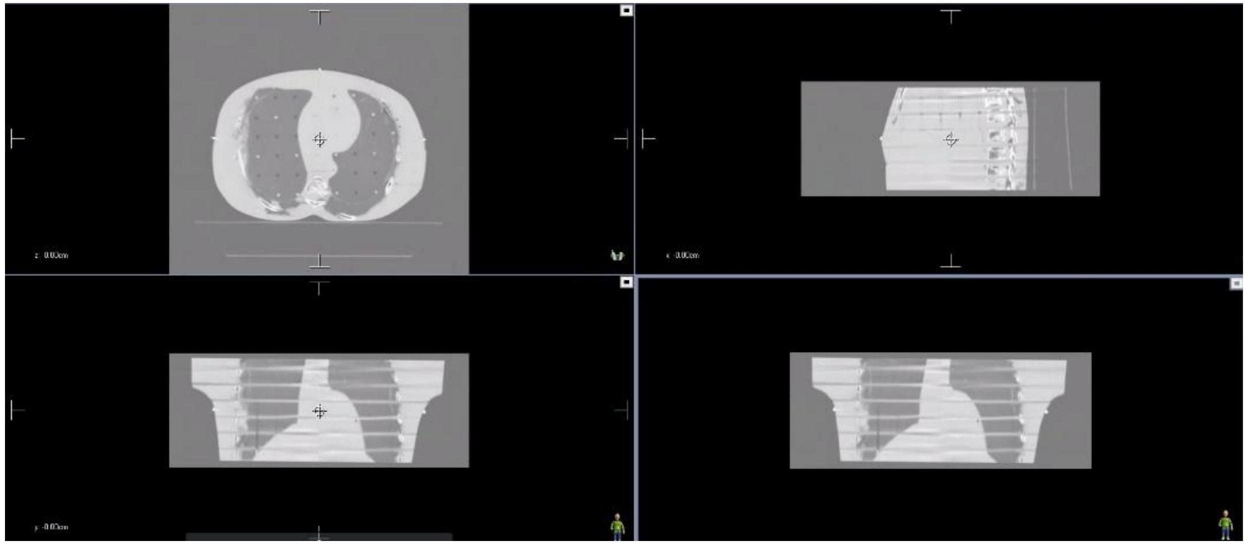


Auto shifts on TrueBeam:
Vert 0.14 Rtn 0
Long -.18 Pitch 0.1
Lat -0.07 Roll -0.2

<u>Dose reduction: 55%</u>

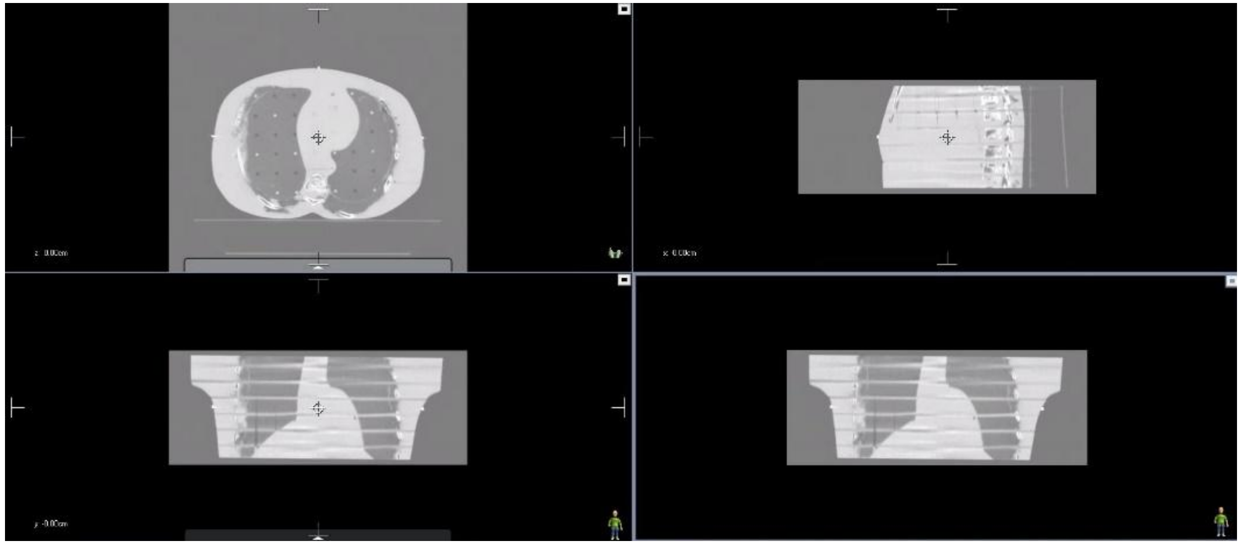
CBCT Imaging Dose Optimization

Standard Thorax Protocol, Varian TrueBeam



Auto shifts on TrueBeam:
Vert -0.15 Rtn 0
Long 0.06 Pitch 0
Lat 0.07 Roll -0.4

mAs reduced by 2/3



Auto shifts on TrueBeam:
Vert -0.15 Rtn 0
Long 0.06 Pitch 0
Lat 0.07 Roll -0.4

<u>Dose reduction: 57%</u>

CBCT Imaging Dose Optimization

NHS
Hull University
Teaching Hospitals
NHS Trust

Optimisation in practice

- Concerns were raised about the imaging dose burden for a **27 year old**, **56 kg** (very slim) patient imaged with Varian default exposure factors of 125 kVp and 80 mA
- Over a couple of fractions, and a few repeat exposures (for setup issues), kVp was dropped to 110 kV, and tube current to 40 mA
- **No adverse affect on image quality, BUT 'DOSE' WAS REDUCED BY A FACTOR OF THREE**

CBCT Imaging Dose Optimization

Optimisation in practice

Hull University Teaching Hospitals NHS Trust

- We were presented with poor image quality on a very large patient (116 kg)
- This exposure was not optimised (or justified) as the Radiographers couldn't see what they were looking for
  - The 'intended purpose' was lost in the noise & artefacts!
- The only option was to increase exposure factors
  - We had to double pulse width (and hence dose) to reduce the noise to improve soft-tissue contrast

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- Imaging dose magnitude is dependent on multiple imaging parameters, as well as patient size
- Imaging dose distribution often has an inhomogeneous nature
- Peripheral dose from imaging is often negligible

Summary and Conclusions

- Imaging dose optimization is warranted as long as it has no detrimental effects on accuracy of treatment delivery
- Use caution when looking up imaging doses!


Questions?