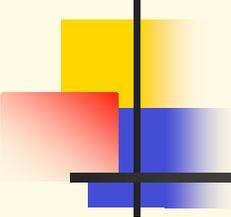


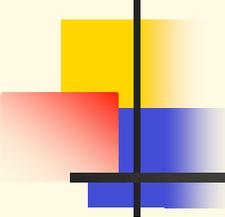
Managing the imaging dose during image-guided radiation therapy

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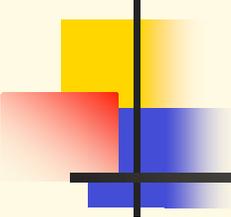
Imaging during radiotherapy

- Radiographic image guidance has emerged as the new paradigm for patient positioning, target localization, and external beam alignment in radiotherapy.
- The AAPM has recognized the importance of imaging dose management by supporting a task group report on the subject:
Murphy M, Balter J, Balter S, BenComo J, Das I, Jiang S, Ma C, Olivera G, Rodebaugh R, Ruchala K, Shirato H, Yin F, *The management of imaging dose during image-guided radiotherapy*, Report of the AAPM Task Group 75, Medical Physics 34(10): 4041 – 4063, 2007.



Outline

- Imaging procedures for radiotherapy
- Dose summation
- Dose evaluation
- Dose reduction
- Summary



Uses of radiographic imaging in Image-guided radiation therapy (IGRT)

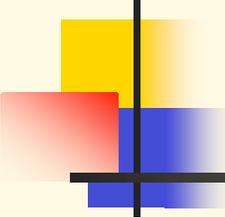
- Precise daily positioning of the patient before treatment
 - MV portal imaging
 - dual kV planar imaging
 - in-room fan-beam and cone-beam CT
- Intra-fraction motion monitoring
 - kV radiography and fluoroscopy
- Daily plan adaptation
 - fan-beam and cone-beam CT

BrainLab Exactrac x-ray



Varian On-board Imager (OBI)





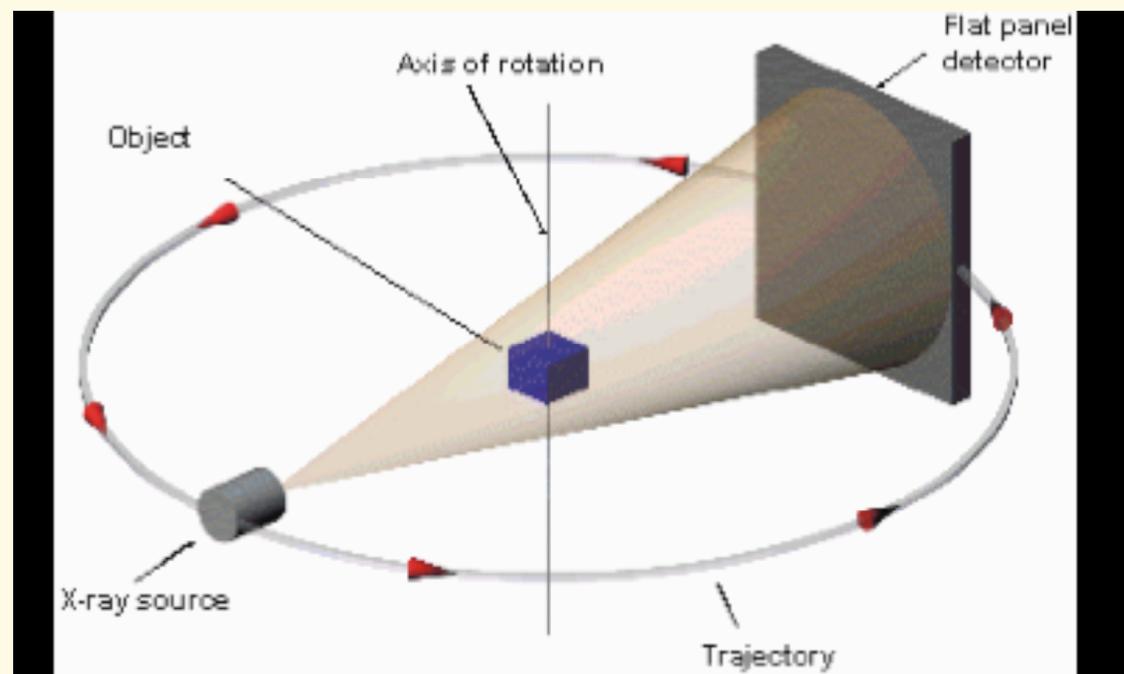
CT on rails

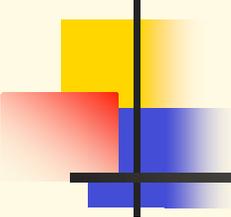


CyberKnife



Cone-beam CT

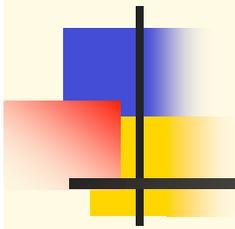


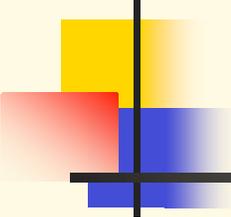


Some IGRT scenarios

- daily pre-treatment CTs for 30 fractions:
60 - 400 mSv
- two pairs of MV portal images daily for 30 fractions:
40 - 400 mSv
- two minutes of daily kV fluoroscopy for 30 fractions:
40 - 120 mSv
- 100 dual kV planar images daily for 5 fractions:
10 - 100 mSv

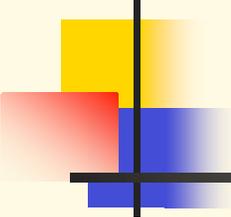
Summing the imaging dose during IGRT





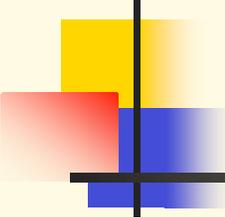
Difficulties in determining the imaging dose during IGRT

- Data for the dose delivered by the various radiographic imaging modalities being used during radiation therapy are presently scattered widely through the literature, making it difficult to estimate the total dose that the patient will receive during a particular treatment scenario.
- IGRT systems often are configured differently than diagnostic imaging setups.



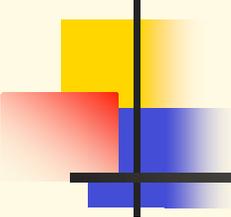
Issues in summing the doses from different modalities

- different imaging scenarios distribute dose in fundamentally different ways, making it difficult to sum dose in a radiobiologically consistent manner:
 - e.g., planar kV imaging dose attenuates rapidly along the line of sight; CT dose is uniformly distributed through the patient
- planar kV dose is evaluated as entrance (skin) dose in air kerma, without scattering; axial kV dose (CT) is evaluated as computed tomography dose index (CTDI), with scattering
- for kV, air kerma and absorbed dose are essentially the same; for MV they are not the same in regions of electronic disequilibrium (e.g., air/tissue boundaries).
- kV surface dose buildup layer is very thin; MV surface buildup layer is much deeper; thus skin doses are very different



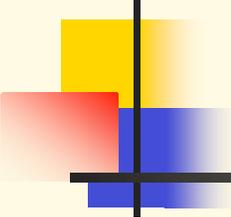
Summing doses

- Because of the differing qualities of kV, planar, CT, and MV exposures, the doses should only be compared and summed in units of “effective dose”, which represents the approximate biological detriment associated with a given integral dose



Effective dose

- The concept of “effective dose” (or effective dose equivalent) was introduced to provide a common framework for evaluating the biological detriment of exposure to ionizing radiation via any means.
- From Jacobi (Radiat Environ Biophys 12, 1975):
“the mean absorbed dose from a uniform whole-body irradiation that results in the same total radiation detriment as from the non-uniform, partial-body irradiation in question.”

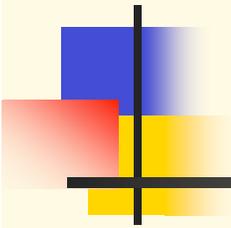


Effective dose

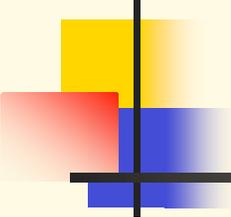
- $E = \sum_T w_T H_T \text{ milliSieverts (mSv)}$

where the H_T are the average organ doses to tissue T for a particular exam and the w_T are tissue weighting factors that represent the relative radiation sensitivities of the organs.

- Unlike local absorbed dose, effective dose is a volume integral and thus depends on both the beam fluence and imaging area

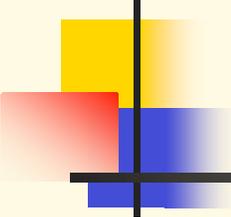


Evaluating the imaging dose



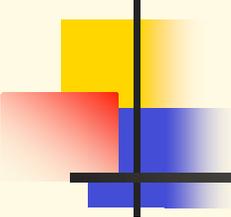
Interpreting risk

- Two categories of risk:
 - deterministic risk – e.g., skin injury, cataracts – has an approximate threshold that can be observed on an individual basis.
 - stochastic risk –e.g, the increased risk of a secondary cancer – is probabilistic and is extrapolated from population-based data.
 - Stochastic risk is estimated from the total effective dose



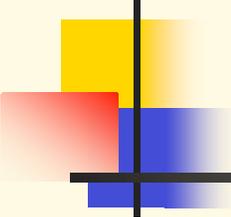
Examples of deterministic risk

<u>Effects</u>	<u>Threshold</u>	<u>Time of onset</u>
■ early transient erythema	2000 mGy	2 – 24 hours
■ Temporary epilation	3000 mGy	1.5 weeks
■ main erythema	6000 mGy	3 weeks
■ permanent epilation	7000 mGy	3 weeks
■ dermal necrosis	15,000 mGy	> 52 weeks
■ eye lens opacity	> 1000 mGy	> 5 years
■ cataract (debilitating)	> 5000 mGy	> 5 years



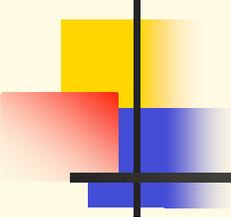
Examples of stochastic risk from IGRT concomitant dose

- 70 year old male with prostate cancer
 - CT for planning (8.2 mSv)
 - 30 daily portal image pairs (30x1.3 mSv)
 - 0.2% risk of secondary cancer
- 30 year old female patient w/ cervical cancer
 - Planning CT (8.2 mSv)
 - 30 daily CTs for positioning (30x8.2 mSv)
 - 1.25% risk of secondary cancer



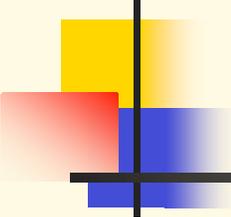
Difficulties in interpreting risk

- Diagnostic imaging and image-guided surgery introduce ionizing radiation, while IGRT adds it to an already considerable therapeutic exposure.
- Increased imaging dose during IGRT can reduce normal tissue exposure to the treatment beam, thus reducing overall concomitant dose.



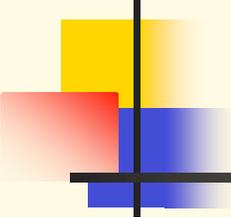
Difficulties in interpreting risk

- not everyone has the same sensitivity – children are 10 times more sensitive than adults; girls are more sensitive than boys, women have different organ sensitivities than men.
- Not everyone is in the same risk category – a seventy year old man undergoing image-guided prostate treatments is in an entirely different risk situation than a 15 year old undergoing image-guided radiosurgery for an AVM on the spinal cord.



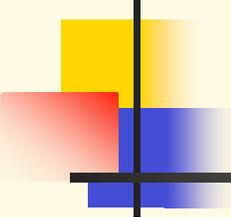
Comparing imaging and therapeutic effective doses

- In addition to the primary therapeutic dose deposited in the target volume we have
 - Primary concomitant dose from beams transiting normal tissue
 - Secondary concomitant dose from internal and external scatter, linac leakage, etc



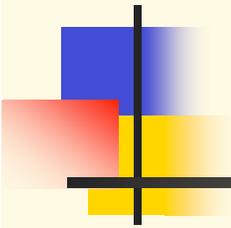
Evaluating imaging dose by comparison to therapeutic dose

- Effective dose is the established way to measure and compare radiation dose in terms of its stochastic risk
- Imaging dose is delivered in standard formats
- Therapeutic dose is delivered in highly variable patient-specific scenarios
- There has not yet been much done to calculate effective doses for therapy
- Therefore it is not yet feasible to make precise quantitative comparisons of imaging versus therapy dose

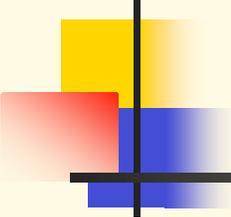


Example dose comparison

- Estimate of 854 mSv effective dose from scattered internal beam and external leakage and scatter for a 70 Gy prostate treatment
 - AA Cigna et al, *Dose due to scattered radiation during external radiotherapy: a prostate cancer case history*, Radiation Protection Dosimetry 108 (1): 27 - 32, 2004.
- Compare to 350 mSv from 35 daily diagnostic quality pelvic CT scans for image-guided adaptive radiotherapy

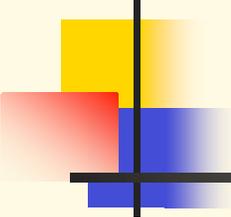


Reducing the imaging dose



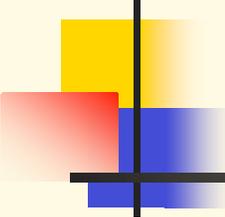
Dose reduction

- In general, for imaging during IGRT one should not assume that diagnostic quality procedures and images are necessary in all applications



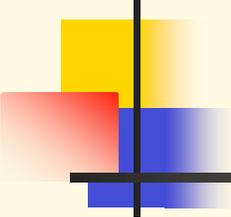
Dose reduction

- Effective dose is a volume integral, so reducing fluence and/or area helps
 - Planar imaging FOV for patient setup can be collimated down to the region of interest
 - CT scan length can be reduced to the region of interest
 - Digital tomosynthesis - CT acquired over a limited angular arc reduces CTDI



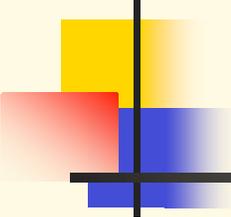
Temporal dose reduction

- Fluoroscopy for target tracking doesn't always require video frame rates (30 frames/second) or a continuous exposure
 - - e.g., respiration monitoring can be done at 2 - 4 frames per second via pulsed fluoroscopy



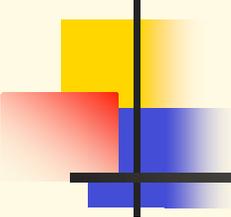
Fluence reduction

- Image registration for patient setup, contour transfer, and dose summing can be fairly insensitive to noise, so the technique can be reduced below diagnostic quality



Reduction by modality change

- Intra-fraction monitoring via kV fluoroscopy can be replaced by cine-mode MV portal imaging using the treatment beam
 - This can work for 3D conformal therapy, where the beam aperture is fixed for each field
 - Cannot work for dynamic IMRT, where the beam aperture is constantly changing



Summary

- Imaging systems and procedures for IGRT are often configured differently than for diagnostic exams, resulting in different doses
- IGRT can combine several different imaging procedures for a particular patient
- Estimation of the total concomitant dose must recognize the variations in dose deposition by using effective dose as the common measure
- Risk evaluation in IGRT is fundamentally different than in diagnostic radiology because the imaging dose is added to a high therapeutic dose
- There is a need for estimates of effective dose for the treatment procedures to enable evaluation of imaging dose in context
- IGRT procedures do not always require diagnostic quality images and thus allow a variety of dose reduction strategies