AAPM 2014

From dose to risk: an uncertain predicament or an ethical mandate?

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Acknowledgement

CARL E. RAVIN ADVANCED IMAGING LABORATORIES

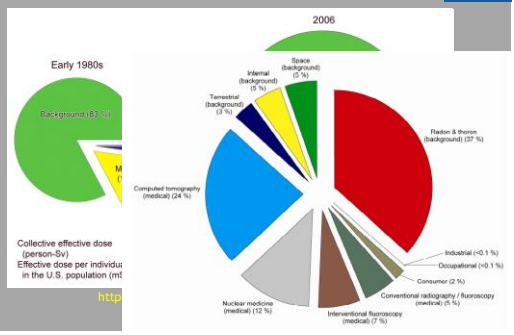
Outline

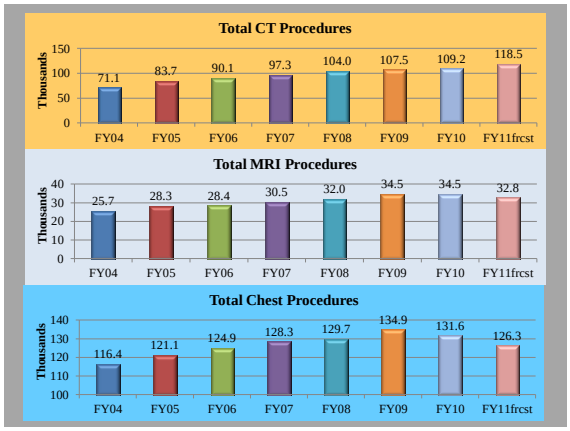
- How to understand risk associated with medical imaging in the context of medical physics:
  - 7 formative questions
- Organ dose in the context of other dose metrics

Imaging quality and safety

- Quality: Imaging provides a clinical benefit
  - Diagnostic information
  - Image quality: Universally-appreciated
  - Enhancement dependent on illusive criteria
- Safety: Imaging involves a level of "cost"
  - Monitory cost
  - Information excess
  - Radiation cost

Increase in Radiation Exposure from Medical Imaging

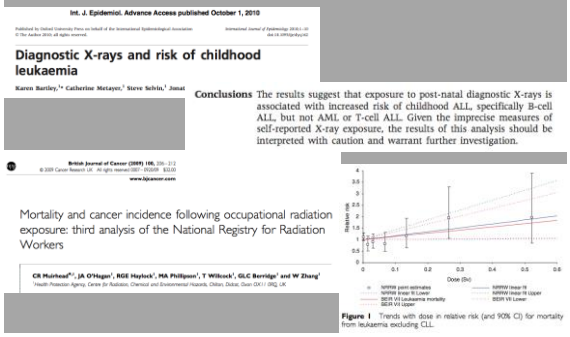




1. Is the increase in the number of imaging exams bad?

- No necessarily so, provided that the exams render the needed medical information
- If benefit > risk, more exams means more benefit!

2. Are low-levels of radiation dose harmful?



Int. J. Epidemiol. Advance Access published October 1, 2010

Diagnostic X-rays and risk of childhood leukaemia

Karen Bartley,[1]* Catherine Metayer,[2] Steve Selvin,[1] Jonat

Conclusions The results suggest that exposure to post-natal diagnostic X-rays is associated with increased risk of childhood ALL, specifically B-cell ALL, but not AML or T-cell ALL. Given the imprecise measures of self-reported X-ray exposure, the results of this analysis should be interpreted with caution and warrant further investigation.

British Journal of Cancer (2009) 100, 206 – 212

www.bjcancer.com

Mortality and cancer incidence following occupational radiation exposure: third analysis of the National Registry for Radiation Workers

CR Muirhead*,[1], JA O'Hagan[1], RGE Haylock[1], MA Phillipson[1], T Willcock[1], GLC Berrington[1] and W Zhang[1]

[1]Health Protection Agency, Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, Oxon OX11 0RQ, UK

Figure 1 Trends with dose in relative risk (and 90% CI) for mortality from leukaemia excluding CLL.

2. Are low-levels of radiation dose harmful?

- Limited epidemiological data
- High degree of uncertainty in risk estimates
- No-threshold model questioned
  - AAPM, HPS, IOMP statements (<50 mSv => ???)
- Yet:
  - Applying reference diagnostic levels
  - 50% of AAPM talks speak to dose
  - ALARA: As low as reasonably achievable

We got to sort out our passive/aggressive attitude towards radiation risk

3. If the benefit >> risk, do we need to worry about risk?

- Yes!
- *Primum non nocere,* "first, do no harm"
- We are healthcare providers bound by an ethical obligation
- **In the face of risk we are obligated to minimize the likelihood of harm no matter how big the benefit**

4. If the risk is uncertain, do we need to worry about risk?

- Yes!
- Uncertainty ≠ absence
- *Primum non nocere,* "first, do no harm"
- We are healthcare providers bound by an ethical obligation
- **In the face of uncertainty we are morally bound to take the safest path**

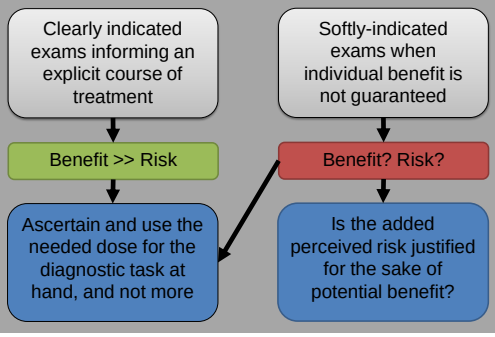
5. Is there such thing as individual risk?

- Yes
- Risk is a statistical construct, likelihood estimated for a population, but ascribed to an individual
- Risk: Inherently uncertain for the individual yet that is what the risk is

6. Is risk additive?

- Yes!
- Even wo repair mechanisms, twice the dose means twice the likelihood of harm, whether the doses are at the same time or 5 years apart
- Counting cumulative or incremental dose for individual exam is up for debate

7. What about the exams when benefit is uncertain?



Dose metrology syntax

Metric	Definition
CTDI	Radiation output of a CT system in a standard sized phantom
SSDE	Radiation output of a CT system adjusted for the average patient size (for chest, abdomen/pelvis scans)
Organ dose	Dose to individual organs; estimated by simulation or experimental measurement
Effective Dose	Weighted sum of organ/tissue equivalent dose for radiation sensitive organs ignoring patient specific factors
Risk index	Weighted sum of organ/tissue equivalent risk for radiation sensitive organs, accounting for age, gender, anatomy

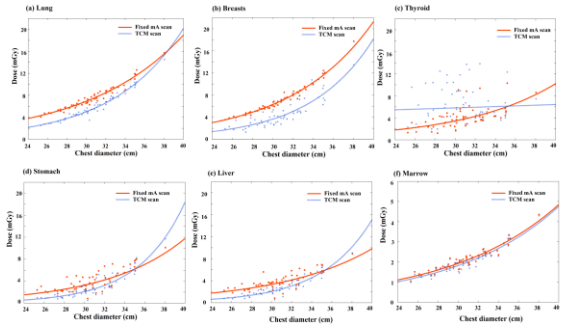
Samei, Ped Rad, in press, 2014

Metric	Measure-able	Modality generic	Scanner model and factors	Patient Size	Patient anatomy	Patient age	Patients Gender	Patient average total burden
CTDI	✔		✔					
SSDE	✔		✔	✔				
Organ dose	✔	✔	✔	✔	✔	✔	✔	
Effective Dose		✔	✔	✔	✔			✔
Risk index		✔	✔	✔	✔	✔	✔	✔

Organ dose: WHY?

- The only dose metric that
  - Accounts for specific patient attributes
  - Is an actual physical quantity (measureable)
  - Can be compared across modalities
  - Can be a solid basis for any risk estimation
- Caveat:
  - Non-scalar metric of radiation burden

Typical organ dose values (chest CT)



Conclusions

- The increased use of imaging exams is a positive trend, not a negative one
- Existence of benefit and uncertainty does not negate the moral obligation for risk mitigation
- Imaging optimization requires individualized metrics of radiation burden
- Organ dose is the most meaningful metric of radiation burden with the caveat of the need for scalarization

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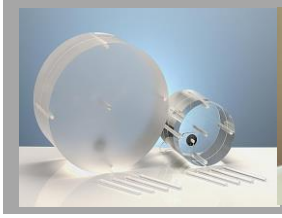

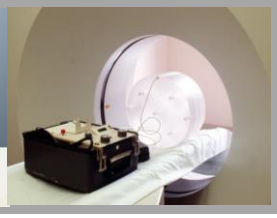

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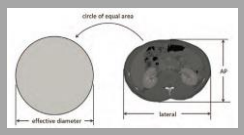
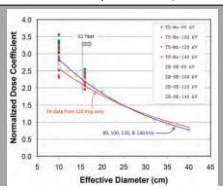
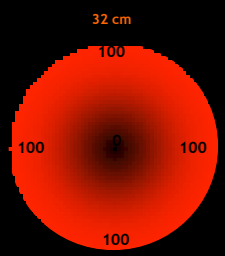


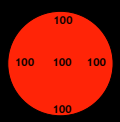


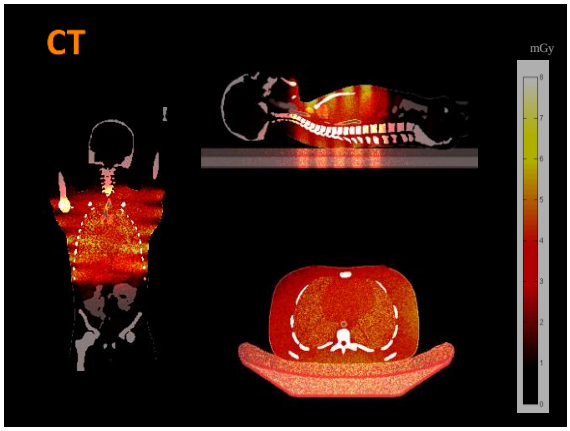
CTDI dose

Body



Head





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Sahbaee, Samei, MP, in press, 2014

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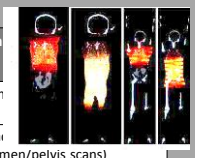

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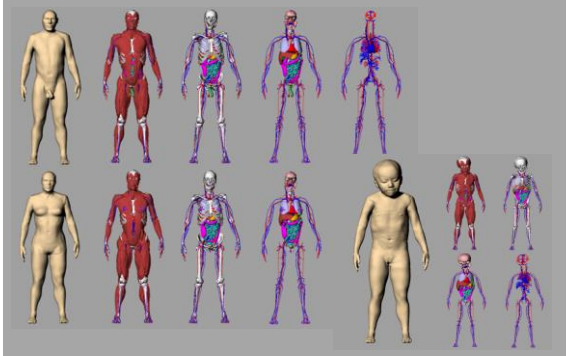
Organ dose: HOW?

- Precise estimation possible only if we overcome 4 challenges
  1. Knowing/modeling patient anatomy
  2. Modeling CT acquisition process
  3. Knowledge of irradiation condition
  4. Integration into clinical operation

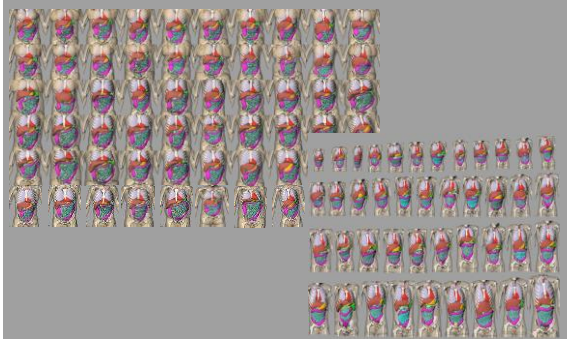
28

XCAT Virtual Patient Models

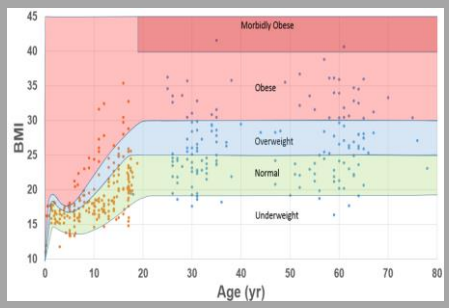


Segars el al, 4D XCAT phantom for multimodality imaging research, Medical Physics, vol. 37 (9), 2010

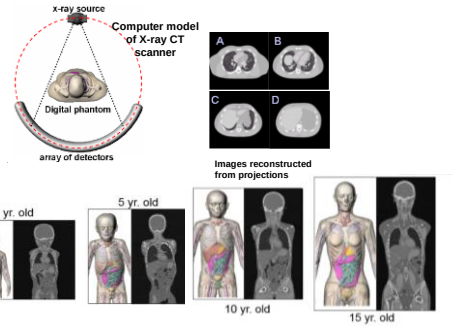
150+ models thus far, building towards 400



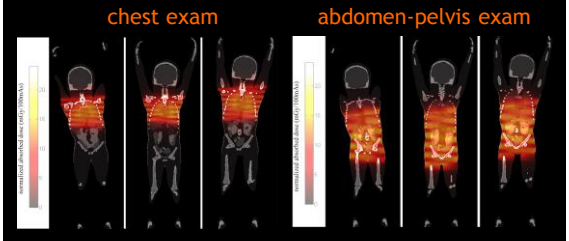
Population Representation



Imaging Simulation

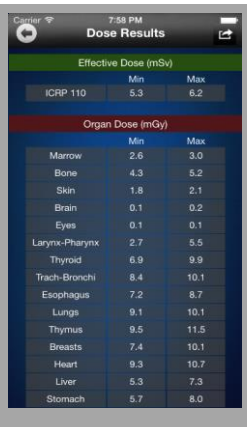


Example Dose Distributions



Li, Samei et al., Med Phys, 38(1), 397-407 (2011).
Li, Samei et al., Med Phys, 38(1), 408-419 (2011).

Patient Specific Dose Calculator iPhone App



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