Estimating the Dose to Organs from Xray Backscatter Scanners: Methods, Estimates, and Open Issues

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Conclusions

- Motivated by claims of XBS radiation dose:
  - 'Doesn't penetrate skin', 'equals 2 minutes air travel'
- Understanding organ dose is important for quantifying risk
- Goal:
  - Given the specs in public domain, what is dose to organs?
  - Compare with estimates in published FDA report
- We made assumptions based on literature, patents, reports
- Used simulations to estimate organ and effective dose
- Results: Radiation distributed throughout body, more dose closer to surface of body. (Example)
- Numerous Limitations: accurate only to order of magnitude
- Dose estimates roughly comparable to FDA report
- Is it safe?

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Units of Radiation Dose

- Absorbed Organ Dose: Gray (Gy)

$$1\ Gy = \frac{deposited\ energy}{mass} = \frac{Joule}{kg}$$

- Effective Dose: Sievert (Sv)

  Formula that weights select organ doses according to tissue sensitivity

Monte Carlo Simulation

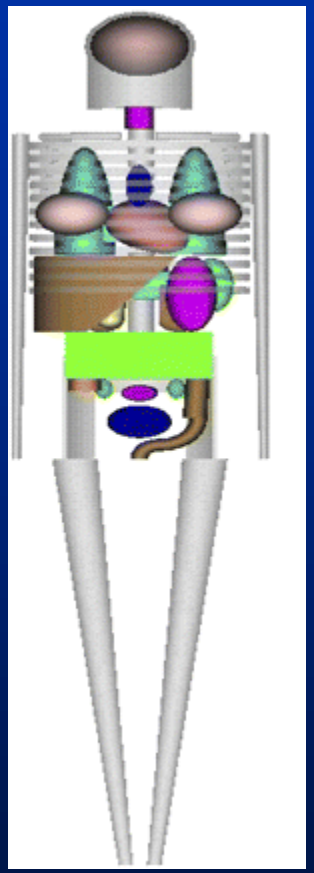
- Model x-ray attenuation properties of materials
- Model the stochastic transport of photons through the materials
- Track photons and sum energy deposited in each material

Previous Studies in Public Domain

- FDA / TSA Study [Cerra 2006]
  - Single-Unit prototype
  - Experimentally measured x-ray beam spectrum and quantity
  - Quantified organ dose using Monte Carlo simulation and mathematical phantoms
  - Quantified effective dose from organ doses
  - Published factors for converting scanner measurements to effective dose

Previous Studies in Public Domain

- Limitations of FDA /TSA Study:
  - Single-Unit scanner
  - Mathematical Phantoms
  - Monte Carlo software designed for diagnostic x-ray imaging



Previous Studies in Public Domain

- Hopkins/TSA Report [2010]
  - Dual-Unit Rapiscan 1000 prototype
  - Experimentally measured x-ray beam spectrum and quantity
  - Quantified effective dose using FDA report conversion values
- Limitations of Hopkins/TSA Report [2010]
  - No independent organ dose estimates
  - Prototype scanner

Previous Studies in Public Domain

- Peter Rez, [Radia. Prot. Dosim. 2010]
  - Estimated the quantity of the x-ray beam from the published images
  - Quantified effective dose using FDA conversion values
  - Found dose 8x higher than Hopkins study
- Limitations of Rez study
  - No independent organ dose estimates
  - Unknown processing may introduce errors

Goal of Our Study

- Given the available system specifications and Hopkins scanner measurements, what is the distribution of dose to the organs?
  - More realistic phantoms than FDA study
  - More flexible Monte Carlo simulation software

Overview of Our Study

- Modeled Rapiscan Secure 1000 Dual-scan system using specs from public domain
- Performed Monte Carlo simulations using phantoms models based on real subjects
- Estimated Organ Dose
- Estimated Effective Dose
- Compared previously published estimates (FDA, Hopkins)

Voxelized Phantoms

- The Virtual Family
  - 34-year-old male
  - 26-year-old female
  - 11-year-old female
  - 6-year-old male
- Obtained from CT scans of cadavers
- Voxel resolution of 2mm x 2mm x 2mm
- 30-31 materials/tissues used
  - Compositions from ICRP Report 110

Specs Required for Simulations

- Scanner geometry
  - position of subject from source
  - dimension and geometry of x-ray beams
- X-ray spectrum and filtration
- X-ray fluence (photons/mm^2)
  - tube output
  - scan time

Not all specs in public domain
Tried to err on the side of higher dose estimates

Simulation Methods

- GEANT4 Monte Carlo Software
- 50 kVp spectrum[1,2] with 1.0 mm Al-filtration[3]
- Scan plane 75 cm from source[4]
- Cone beam irradiating 6-mm x 1000 mm area at scan plane.
- Cone beam translated in vertical direction
- Estimated photon fluence from published exposure meaurements[2]

[1]F. Cerra, 2006
[2]Johns Hopkins, 2010
[3] ANSI, 2009
[4]S.Smith, 1993

After Publication: Letter from NIST

- Glover and Hudson pointed out two errors in our assumptions for estimating photon fluence [Med Phys 39 (9) 3012]
- Correspondence disclosed distance between x-ray source and panel
- Net result: Our published study overestimated dose by factor of 1.25-1.65
- Correction issued [Med Phys 39 (9) 2012]

One goal of study was to generate such discussions

Results: Selected Organ Doses

	Adult male (μGy)	Adult female (μGy)	Male child (μGy)	Female child (μGy)
Skin	0.048	0.051	0.054	0.050
Adipose	0.197	0.258	0.267	0.269
Testes/Ovary	0.039	0.010	0.040	0.013
Breast	N/A	0.023	N/A	N/A
Eye Lens	0.036	0.034	0.028	0.030
Lung	0.0124	0.017	0.019	0.017

Effective Dose Comparison

Study	Scanner	Phantom	Age	Height (m)	Weight (kg)	Eff. Dose (μSv)
FDA/TSA	Single unit	Adult	30	1.74	71	0.0372
		Child	5	1.09	19.1	0.0236
TSA / Hopkins	Dual-unit	-	-	-	-	0.0155
Our Study	Dual-unit	Adult Male	34	1.77	72.4	0.0149
		Adult Female	26	1.63	58.7	0.0165
		Male Child	6	1.17	19.3	0.0218
		Female Child	11	1.47	35.4	0.0157

Summary of Our Dose Results

- Organ doses: 0.3 μGy or lower
  - Dose distributed throughout subject
  - Generally more dose to superficial organs
  - Less dose than eye lens receives during mammogram
- Effective doses: 0.01 – 0.02 μSv
  - ANSI standard is 0.25 μSv

Limitations of Our Study

- Depends on exposure measurements published in Hopkins/TSA report
  - Accuracy of equipment?
  - Prototype scanner versus product?
  - Not an independent measurement
- Errors in modeling scanner geometry
- Possible errors in phantom segmentation

Not accurate enough to answer questions of safety

Future work: Improve Accuracy

- More accurate photon fluence estimates
  - more accurate dosimetry equipment?
  - measured on production scanners
- Improved voxelized phantoms
  - Better segmentation of organs
- Model exact scanner geometry
  - Not all specs currently available

How to Allay Public Concerns?

- Improve accuracy of dose estimates under normal operation
  - Third-party study
- Inform public on quality control and safety measures
- Quantify individual risk and population risk using accurate dose estimates
  - Controversial