Pediatric Imaging in Radiology & Radiation Therapy

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Conflicts of Interest: none

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Educational Objectives

- Radiation dosimetry in diagnostic imaging
  - Review current state of patient-specific dosimetry
  - Discuss strategies to aggregate radiation dose in multi-modality imaging
    - Provide examples for COG based:
      - Neuroblastoma & Wilms' tumor patient populations
  - Discuss dose management strategies and limitations
- Radiation dosimetry for Image Guided Radiotherapy (IGRT)
  - Discuss current use of imaging during therapy
  - Provide examples for dose values
  - Discuss dose reduction strategies for IGRT

Educational Objectives

- Goal: calculate radiation dose burden from all forms of imaging
  - Dx: x-ray, CT, Nuc Med, PET, & fluoroscopy
  - Tx: CBCT, x-ray, orthogonal x-ray, fluoro
- Challenge to understanding complete dose picture involves:
  - Data collection & interpretation
    - Each modality has unique geometry constraints
    - Each modality has unique dose descriptors
    - How do we collect and analyze the data?

Data Collection: National & Local

- National databases
  - ACR; National radiology data registry (NRDR)-Dose index (> 50 M studies)
  - Bayer (all customers, state of NJ, U of California hospitals)
  - Siemens (all customers)
- Local databases (limitations):
  - Only account for CT radiation dose
  - Some account for fluoro & Nuc Med/PET but do not aggregate the doses
  - A Walk Through the Market-Dr. Sarah McKenney (SPR/RSNA)
    - 16 vendors
    - https://goo.gl/CMRpjt

Data Interpretation

- Infrastructure is present for data collection
  - Lacks aggregation of all ionizing radiation modalities
- Limited means to compare inter-modality imaging dose
  - Each modality has its own dose metric

CT — Fluoroscopy — X-ray — Nuc/PET

CTDIvol, DLP, SSDE, air kerma, KAP/DAP, EI/DI, KAP/DAP, MBq/mCi

→ Effective Dose

Population based

Age/sex independent

Data Interpretation

- How can we be more patient-specific for dosimetry?
  - Develop the science to relate each dose metric to organ dose

CT — Fluoroscopy — X-ray — Nuc/PET

CTDIvol, DLP, SSDE, air kerma, KAP/DAP, EI/DI, KAP/DAP, MBq/mCi

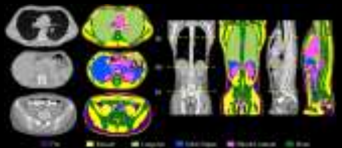
→ Organ Dose

Patient specific

Age/sex/weight/size dependent

Computed Tomography

- Calculate patient dose from CT examinations
  - Monte Carlo (Gold Standard)
    - Patient-specific requires organ-based segmentation
    - Fully automated (machine learning) tissue segmentation
      - Accuracy-(DSC): lung-0.98, fat-0.90, muscle-0.85, solid organ-0.75, blood/contrast-0.82, and bone-0.90
    - Still need fully automated organ segmentation

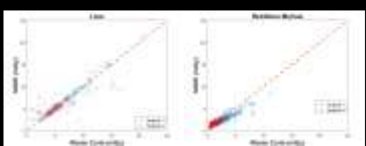


Somasundaram, et al. Phys Med Bio. 63 135009, 2018

Computed Tomography

- Calculate patient dose from CT examinations
  - Monte Carlo
    - Population-specific requires computational phantoms
  - Size specific dose estimate (SSDE)*
    - Limitation: head SSDE not defined yet

MIRD phantom; ORNL *NCAT phantom; Duke*



Moore BM, Brady SL & Kaufman, RA; Med Phys 41(7) 2014, 071917

Nuclear Medicine & PET

- Radiopharmaceutical kinetic models derived for age specific bio-distribution
  - Derived from MIRD formulation

$$d(r_T, T_D) = \sum_{r_S} \left(\frac{1}{A_0} \int_0^{T_D} A(r_S, t)\,dt \right) \cdot \left(\frac{1}{M(r_S,t)} \sum_i E_i Y_i \phi(r_S \leftarrow r_S, E_i, t) \right)$$

  - Calculated by MIRDOSE/Olinda software
- Online calculators
  - RADAR website* & SNMMI website**
- Take ICRP discretized data
  - Fit the data for patient dosimetry of all ages

$$D_{organ}(mGy) = PD(mCi) * 37 \left(\frac{MBq}{mCi} \right) * A \left(\frac{mGy}{MBq} \right) * age^B$$

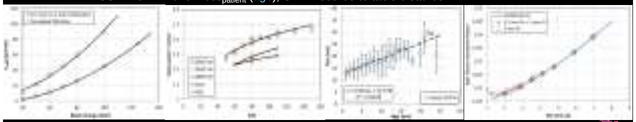
  - *PD*: pharmaceutical dose
  - *A*: ICRP organ dose value
  - *B*: organ specific parameter (e.g., colon = -0.53

*http://www.doseinfo-radar.com/RADARDoseRiskCalc.html
**http://www.snmmi.org/ClinicalPractice/doseTool.aspx?ItemNumber=11216&navItemNumber=11218

X-Ray and Fluoroscopy

- Calculate patient dose from DR examinations*
  - Fluoro is mostly the same except uses dose rate
  - (1) characterize machine output & (2) use examination metadata
  - $ESD = k_{air} * BSF * \left(\frac{SCD}{SSD}\right)^2 * \left(\frac{\mu_{en}}{\rho}\right)_{air}$; ESD ≡ entrance skin dose
    - $k_{air} = (0.0093 * kVp^2 - 0.0165 * kVp) * mAs$
    - $BSF = 0.18 * ln(kVp) + 0.57$
    - SSD = STD – $\text{thickness}_{patient}$ (age); STD ≡ source to table distance

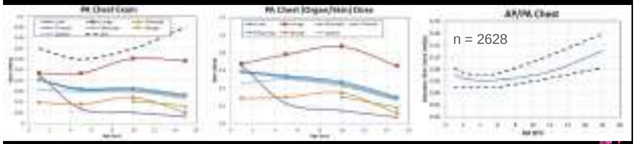
Metadata text



*Brady, SL & Kaufman, RA; Med Phys 42(5) 2015, 2489-2497

X-Ray

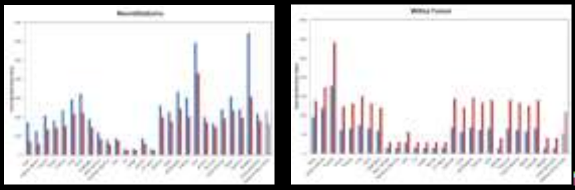
- To calculate other organ dose:
  - Monte Carlo (PCXMC) code & mathematical phantoms*
  - Create organ/skin conversion factors
  - Apply factors to your institutional ESD



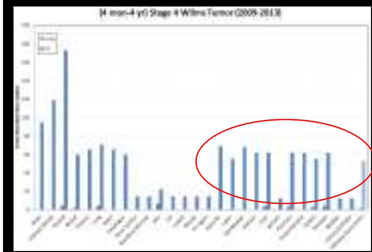
*Ladia et al, J of physics conf series 637 (2015) 012014

Aggregate Patient Organ Dose

- IRB approved retrospective study
  - Neuroblastoma: 74 patients
  - Wilms' tumor: 80 patients



Aggregate Patient Organ Dose



Diagnostic Ionizing-radiation Examinations (n = 45±11)

- XR (n = 28±8)
  - 1.6 mSv (~0.06 mSv/exam)
- CT (n = 17±8)
  - 53 mSv (~3 mSv/exam)
- SPECT/CT (n = 0)
- PET/CT (n = 0)

Omitting Pelvic CT from routine off-therapy follow-up

- Pelvic relapse symptomatic
  - Dose savings: 30-45%

Kaste, S.C., et al.; Cancer Jan 1, 2013; DOI: 10.1002/cncr.27687

Aggregate Patient Organ Dose

Diagnostic Ionizing-radiation Examinations (n = 51±9)

- XR (n = 18±11)
  - 0.4 mSv (~0.02 mSv/exam)
- CT (n = 16±4)
  - 45 mSv (~3 mSv/exam)
- SPECT/CT (n = 14±1)
  - 126.2 mSv (~9 mSv/exam)
- PET/CT (n = 3±3)
  - 60.2 mSv (~12 mSv/exam)

Omitting chest CT from routine off-therapy follow-up

- Chest relapse symptomatic
  - Dose savings: 45%

Frederico, S., et al.; Ped Blood Cancer 62(), 2015; 976-981

Dose Management Strategies

Multi-modality general dose management strategies

Designing Pediatric Imaging to Achieve the Best Benefit/Risk for Our Patients (Wed 10:15; Rm 202)

- CT
  - Size based optimization (TCM, ODM, etc.)
  - Enhanced reconstruction algorithms (iterative recon, deep learning)
- X-ray
  - Size based protocols
  - Increased filtration
- Fluoro
  - General fluoro dose rates ≤ 7.5 fps (line placement can be as low as 1-2 fps)
  - Enhanced filtration & software (smart denoising algorithms)
  - Shorter pulse widths for peds
- PET & SPECT
  - Weight based pharmaceutical dosing
  - New digital technology has the potential to reduce injected dose by
  - Lower CTAC dose

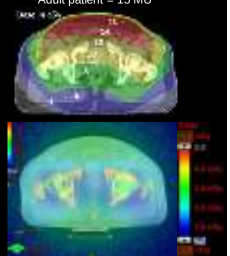
Image Guided Radiotherapy (IGRT)

- IGRT has become standard in most radiotherapies
  - Portal imagers
  - X-ray/fluoro/cone beam flat panel system
  - Floor mounted orthogonal system
- Imaging for IGRT is often performed daily
- Need to consider implications for imaging for therapy delivery
  - Dose to sensitive organs, secondary cancers, etc.
- AAPM Reports 95 & 180
  - TG180: recommend considering impact of therapy regiment when imaging dose ≥ 5% therapeutic dose (PVT)
    - E.g., CBCT can add upwards of 1-3% of PVT total dose

Image Guided Radiotherapy (IGRT)

- Cone beam CT (CBCT)
  - Exposes normal tissue when used
- MV-CBCT using EPID
  - Can exceed 100 mGy
  - Siemen's Artiste has 4.2 MeV e^- carbon target
    - Improved soft tissue contrast
    - 1/3 MV radiation dose
- kV-CBCT (e.g., OBI or XVI)
  - Typically 10-50 mGy (lower by ~10x from a decade ago)
  - Better dose management
    - Lower kV (100 or 110 vs. 125 kV)
    - Better collimation
    - Sparse angle reconstruction (e.g., 200 views vs. 360)

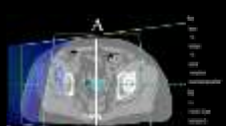
Adult patient = 15 MU



**TG180

Image Guided Radiotherapy (IGRT)

- Planar x-ray
  - Single plane & Fixed floor orthogonal units
    - ~10 mGy
  - Use of Bow-tie filters*
    - Improves image quality & reduces dose
  - In some cases the # of acquired planar images may exceed 80/treatments**



- Fluoroscopy
  - $D \propto time$
  - 5-11 mGy/min (30 fps, 100 – 120 kV, @ isocenter)
  - Dose reduction using pulse rates < 30 fps

*Ding and Munro; Radiother Oncol. Jul 2013;108:91–98
**TG180

Image Guided Radiotherapy (IGRT)

- AAPM Report 95: The management of imaging dose during image-guided radiotherapy ('07)
- Estimated effective dose for a treatment regiment (e.g. 30 fractions)*
  - Daily pre-treatment CTs (60-400 mSv)
  - 2 pairs of MV portal images (40-400 mSv)
  - 2 mins of daily fluoro (40-120 mSv)
  - 100 orthogonal kV images (10-100 mSv)

*M. Murphay PhD, Managing the imaging dose during image-guided radiation therapy. AAPM 2009

Example (*combination real & hypothetical*)

- mIBG avid Stage 3 NB patient (*represents a generic high risk patient*)
  - Dx imaging over 4-5 years resulted in
    - X-ray: 0.5 mSv
    - CT: 45 mSv
    - PET/CT: 60 mSv
    - SPECT/CT: 126 mSv
  - Tx imaging from a 14 fraction course
    - Daily CBCT setup: 60 mSv
    - Daily fluoro tracking: 20 mSv
  - Total dose burden ~300 mSv

Conclusion

- Pediatric Tx patients are most sensitive to secondary cancer
  - Alternative is most likely death
  - No question that radiation dose from imaging is beneficial
- No longer can we say imaging dose is negligible in the context of therapy
  - Aggregate Dx imaging along with Tx imaging
- Still room to adopt better dose management

Conclusion

- Still need better dose reporting and storage capabilities
- Scientific field continuing to develop methods to combine multi-modality imaging dose
- Need to aggregate all imaging dose throughout hospital enterprise
  - Radiology
  - Rad Onc
  - Ortho
  - Cardiology
  - etc.

Thank you

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