Dose Reduction Strategies in CT

Mahadevappa Mahesh, MS, PhD, FAAPM, FACR, FACMP, FSCCT.
Associate Professor of Radiology & Cardiology
Chief Physicist - Johns Hopkins Hospital

The Russell H. Morgan Department of Radiology and Radiological Science
Johns Hopkins University, Baltimore, MD

2011 Joint AAPM/COMP Meeting, July 31 – Aug 4, 2011, Vancouver, Canada

Radiation Injuries in CT – Rare but possible!

The New York Times

Health

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

THE RADIATION BOOM

After Stroke Scans, Patients Face Serious Health Risks

By WALT BOGDANICH
Published: July 31, 2010

When Alain Reyes's hair suddenly fell out in a freakish band circling his head, he was not the only one worried about his health. His co-workers at a shipping company avoided him, and his boss sent him home, fearing he had a contagious disease.

FACEBOOK
TWITTER
RECOMMEND
COMMENTS

The New York Times® Reprints

This copy is for your personal, noncommercial use only. You can order presentation-ready copies for distribution to your colleagues, clients or customers here or use the "Reprints" tool that appears next to any article. Visit www.nytreprints.com for samples and additional information. Order a reprint of this article now.

March 5, 2011

West Virginia Hospital Overradiated Brain Scan Patients, Records Show

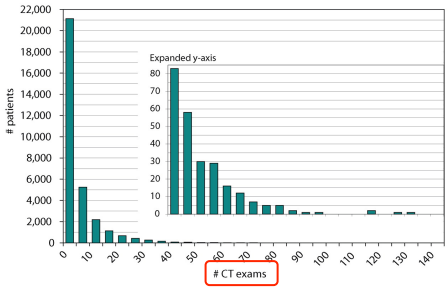
By WALT BOGDANICH

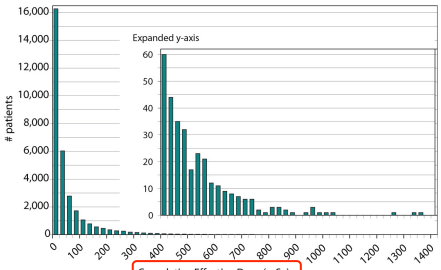
A large West Virginia hospital seriously overradiated patients suspected of having strokes with CT scans for more than a year after similar episodes prompted federal officials to alert hospitals nationwide to be especially careful when using those types of scans, interviews and documents show.

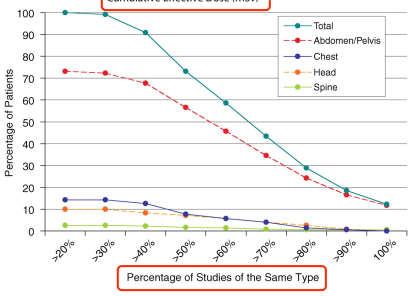
NY times

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Recurrent CT, Cumulative Dose and Cancer Risks







- 22 year study - 31463 patients
- CT: 22 scans in 5%, 38 scans in 1%
- Cumulative Dose:
  - 15% received >100 mSv
  - 4% over 250 mSv
  - 1% over 399 mSv
- CT abdomen and Pelvis is most common repeat exam among patients

Sodickson, A. et al. Radiology 2009;251:175-184

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Introduction

- Optimization of MDCT protocols requires thorough understanding of all technical aspects of CT
  - Relevant scan parameters
  - Dose reduction techniques
  - New technological advances
- Scan and technical parameters are to be tailored to
  - Patient size
  - Body region
  - Clinical questions
- Diagnostic image quality should not be compromised in the effort of reducing dose

Radiation Dose Reduction Strategies

- Optimal tube current (mA) selection
  - Dose modulation strategies
- Reduce tube voltage in suitable patients
- Minimize scan range
- Dynamic collimation
- In Cardiac Imaging
  - ECG gated tube current modulation
  - Prospectively ECG-triggered axial scanning
- Iterative Reconstruction
- Dose Reports
- Dose Check®…

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Factors affecting Radiation Dose and Image Quality

Primary Factors

- Tube Current (mA)
- Tube Voltage (kVp)
- Scan Time
- Pitch
- Scan Acquisition Type

Secondary Factors

- Scan Field of View (SFOV)
- Display Field of View (DFOV)
- Beam Collimation
- Reconstructed Slice Width
- Reconstruction Interval
- Reconstruction Algorithms

Other Factors

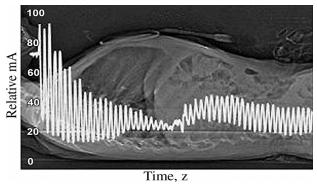
- Patient Size
- Scan Length
- Patient Motion
- Geometry and Detector Efficiency
- Training and experience

CT Dose Modulation

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Automatic Tube Current Modulation (ATCM)

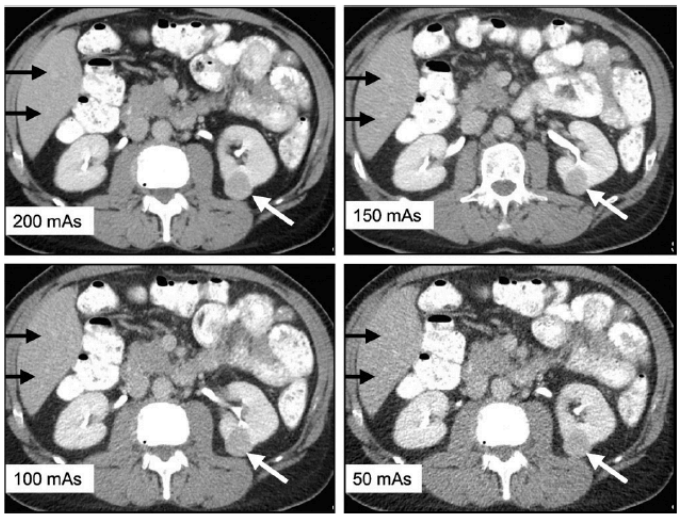
- Tube current modulation available:
  - Smart mA (GE), Care Dose (Siemens)
  - Sure Exposure (Toshiba), Z-DOM (Philips
- For Pediatric CT scans, requires special attention such as
  - Positioning of patients (isocenter)
  - User defined parameters (reference mAs or noise index, Anatomical region, etc…
- Need to analyze whether ATCM is really effective or can dose reduction be simply achieved by modifying scan parameters (mA or kVp) manually



Tube current as function of time (hence table position) during spiral CT of 6 year child
(RadioGraphics 2006; 26: 503-512)

Tube Current: Radiation Dose vs Image Noise

- Renal Cyst (white arrow) observed at all 4 radiation dose levels
- Conspicuity of small liver vessels is compromised at 50 mAs



JACR, 8(5): 369-372, 2011

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

CT dose reduction by Tube Voltage modulation

- Modulating tube voltage based on the patient size
- Lower tube voltage improves image contrast and reduce dose
- As tube voltage decreases, tube current is increased to maintain image noise
- Specially effective during CT Angiography procedures
- New feature

CT Dose Reduction by Tube Voltage Modulation

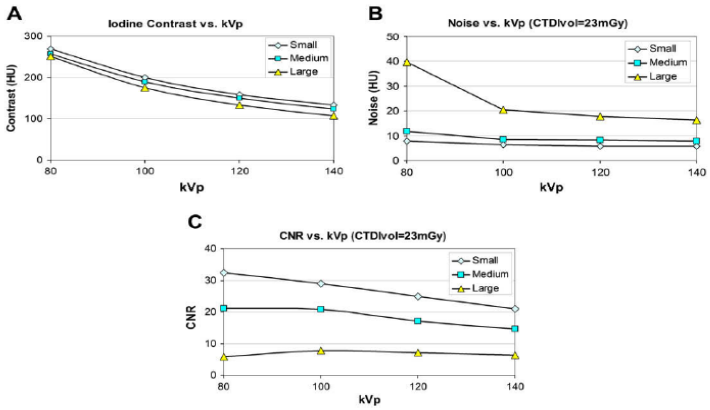


Fig. 3. (*A*) Graph of the CT number of a 2% iodine solution for small, medium, and large phantoms at various x-ray tube potentials. (*B*) Graph of noise (standard deviation of CT numbers within the water background) in images of small, medium, and large phantoms at different tube potentials. (*C*) Graph of the contrast-to-noise ratio (CT number of iodine solution divided by the background noise level) in small, medium, and large phantoms at different tube potentials.

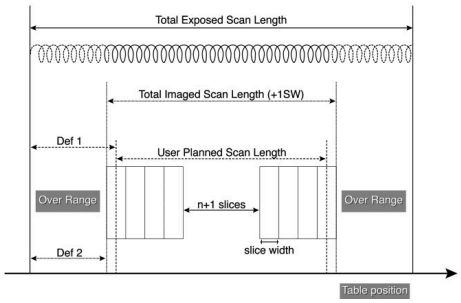
McCollough M, et al., RCNA, 2010

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Over-ranging in CT scans

Over-ranging in MDCT

- Over-ranging is specific to reconstruction-algorithm
- Generally increases with collimation and pitch
- Over-ranging may lead to substantial but unnoticed exposure to radiosensitive organs

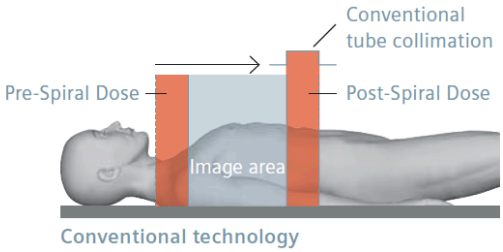


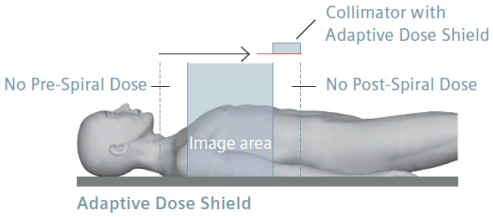
Geleijns, J. Radiology 242(1): 209-216, 2007

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Adaptive Dose Shield

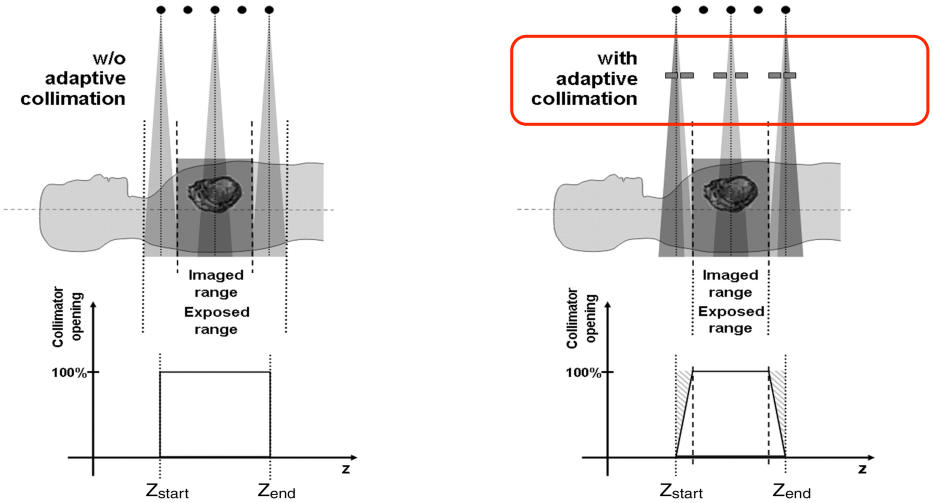
- Conventional pre-patient collimator results in over-scanning
- Adaptive dose shield minimizes radiation to target region and reduces overall dose





Siemens

Conventional and Adaptive Collimation

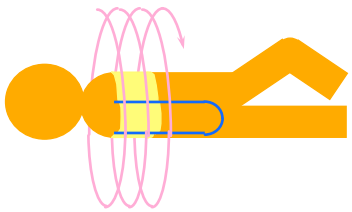


Deak, P. D. et al. Radiology 2009;252:140-147

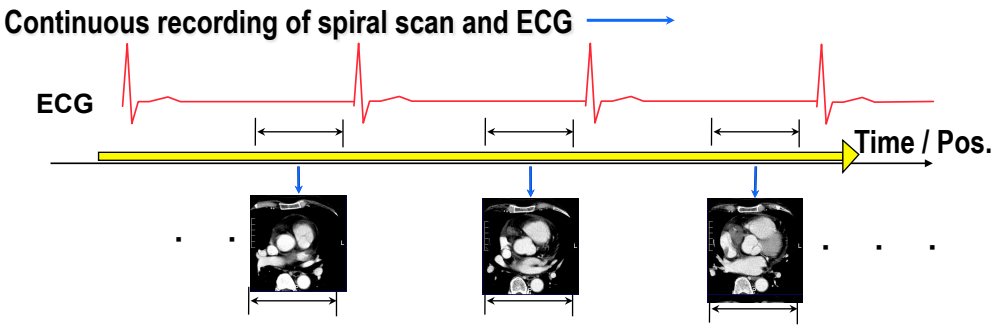
© Mahadevappa Mahesh, MS, PhD, FAAPM, FACR, FACMP, FSCCT.
mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Dose Reduction during Cardiac CT Imaging

Retrospective ECG Gating

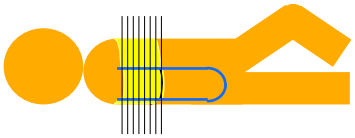


Temporal Resolution
Radiation dose higher than prospective triggering



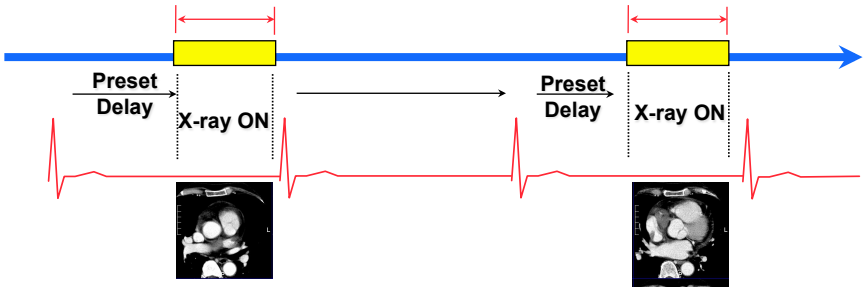
mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Prospective ECG Triggering



Temporal resolution
Radiation dose minimized
Limited data set

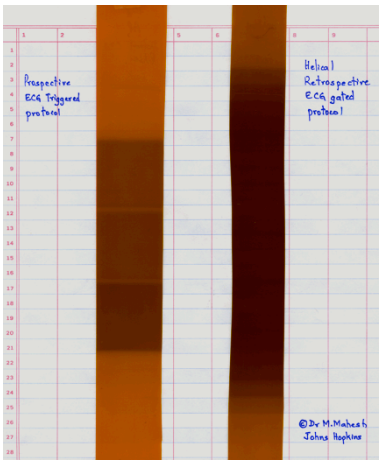
Conventional Axial " Partial Scan " (Step and Shoot)



Coronary CT Angiography:
Prospective Triggered vs Helical Retrospective gated

Effective dose for CTA portion:

4-6 mSv



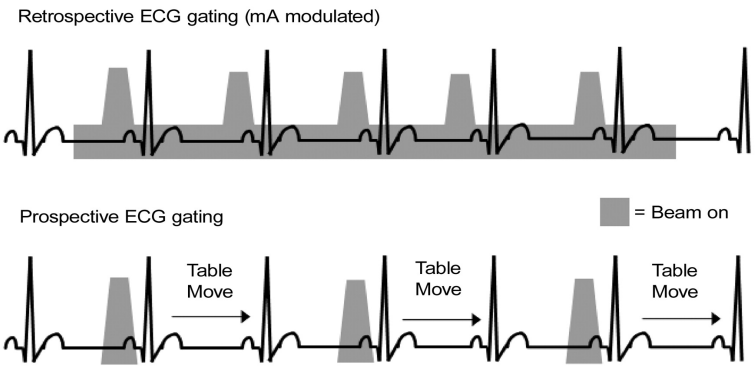
Effective dose for CTA portion:

12-15 mSv

Javadi M, Mahesh M, et al., J Nucl Cardiol 2008

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

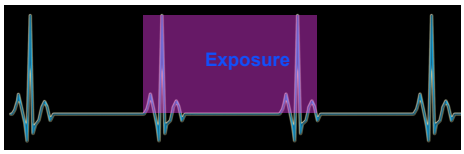
Retrospective ECG gating versus Prospective ECG gating



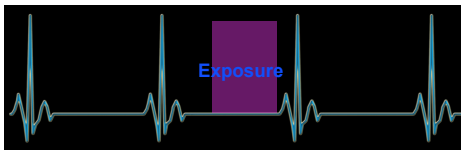
Shuman, W. P. et al. Radiology 2008;248:431-437

320 MDCT: Cardiac CTA Protocol Single Heart Beat Protocol (for HR ≤ 65 bpm)

Single Heart Beat Protocol (for HR ≤ 65 bpm)

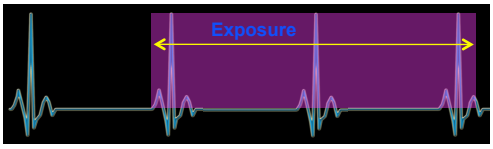


Without ECG Dose Modulation*



With ECG Dose Modulation

2-Heart Beat Protocol (for HR ≥ 65 bpm)

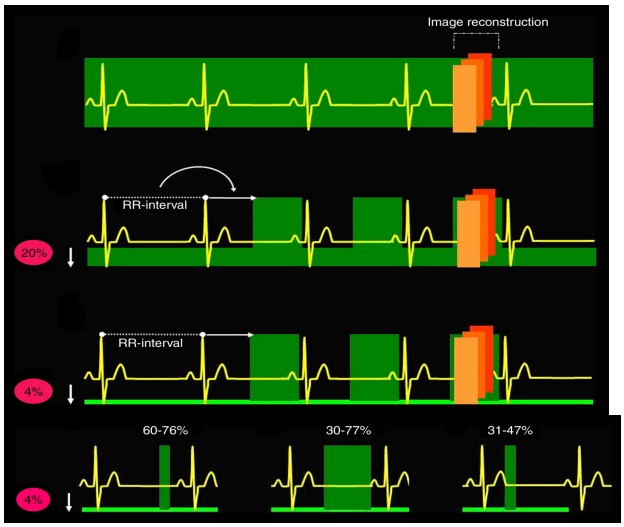


Without ECG Dose Modulation*

Toshiba

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

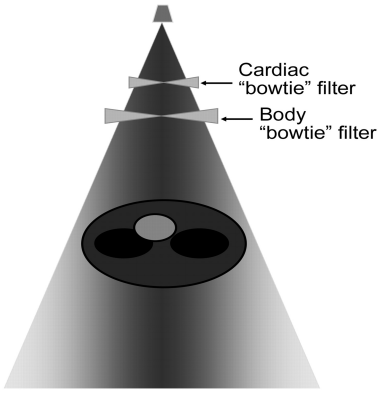
Cardiac CT Imaging with DSCT



Weustink, A. C. et al. Radiology 2009;252:53-60

Beam shaping filters specific to cardiac CT

- Body and targeted field-of-view (cardiac) beam shaping filters
- Radiation dose outside the cardiac region can be lowered



Radiology 2007;243:775-784

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

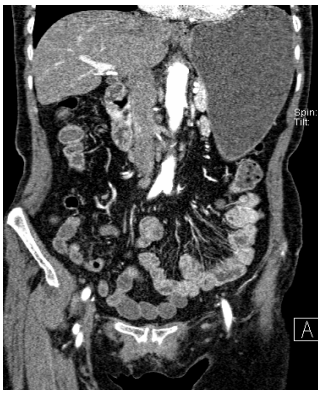
Iterative Reconstruction

Iterative Reconstruction

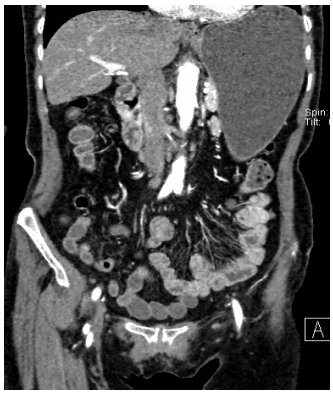
- Conventionally filtered back-projection has been the choice of CT image reconstruction
- Iterative reconstruction method makes several passes over the raw data (obtained at low dose techniques) to produce more accurate model of image and reduce amount of noise
- Can result in 40 to 80% reduction in radiation dose
- Trade-off: need for more processing power and additional time for the process

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Iterative Reconstruction - Noise Reduction



Standard reconstruction



2 Iterations

Standard

2 Iterations

Courtesy: Dr. Mark Baker, Cleveland Clinic Foundation, Cleveland, OH

SIEMENS

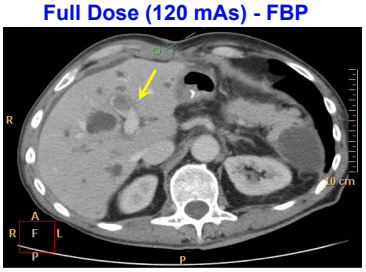
Comparison Full Dose / Dose Reduction 50% + iDose

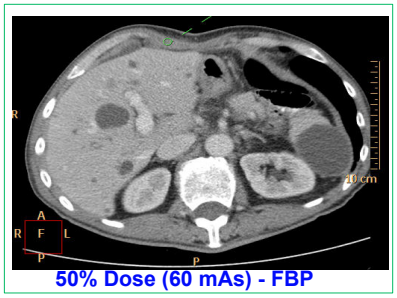
120kV, 120/60 mAs

Apart from the cysts, the first CT shows thrombus in portal vein. On the follow up study, (6 weeks later) the thrombus has disappeared.

Follow up with 50% Dose Reduction

Full Dose (120 mAs) - FBP





50% Dose (60 mAs) - FBP

iDose

50% Dose (60 mAs) + iDose

Philips

Courtesy Dr Dobritz, TU Munich, Germany

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Dual Energy CT (DECT) approaches

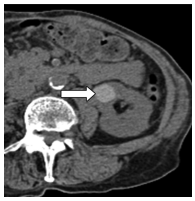
- Dual x-ray tube – each tube set at different kVp (Siemens Dual-Source CT)
- Switching kVp on fly to obtain dual energy CT data (GE)
- CT detector in sandwich form – yielding dual signal for each exposure
- Photon counting detector with energy resolving capability

Triple Phase CT Protocols: Virtual vs True Non-enhanced Images

- Typical triple phase CT protocols
  - True non-enhanced + arterial + delayed phase
- Virtual non-enhanced images with DECT equivalent in image quality with true non-enhanced images
- Reduces dose by nearly 35%

DE Nephrographic Phase

Virtual non-enhanced



True non-enhanced

Graser A et al. Radiology 2009;252:433-440

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

CT Dose – Positive Developments

- Increased awareness
  - Such as *Image Gently®* and *Image Wisely®* campaign
- American College of Radiology
  - Appropriateness Criteria
  - CT Accreditation program
- Education and Radiation awareness

ACR® Appropriateness Criteria*

- Evidence based guidelines to assist referring physicians and other providers in making most appropriate imaging or treatment decision for a special clinical condition
- Guidelines are developed by expert panels in diagnostic imaging, interventional radiology and radiation oncology
- As of 2010, AC is available for 169 topics

* http://www.acr.org/secondarymainmenucategories/quality_safety/app_criteria.aspx

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Last review date: 2010

American College of Radiology
ACR Appropriateness Criteria®

Clinical Condition: Colorectal Cancer Screening

Variant 1: Average-risk individual: age >50 years.

Radiologic Procedure	Rating	Comments	RRL*
CT colonography every 5 years after negative screen	8		☢☢☢
X-ray barium enema double-contrast every 5 years after negative screen	7		☢☢☢
X-ray barium enema single-contrast every 5 years after negative screen	4	If cannot perform double-contrast BE or CTC.	☢☢☢
MR colonography every 5 years after negative screen	4		O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Relative Radiation Level Designations

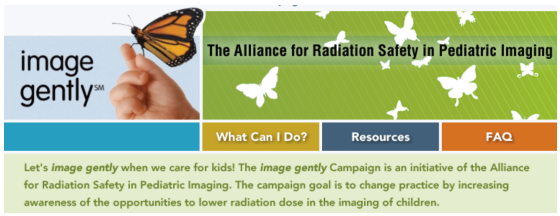
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as NS (not specified).

Variant 5. Relative radiation level designations

Relative Radiation Level	Effective Dose Estimate Range (mSv)
None	0
Minimal	<0.1
Low	0.1–1
Medium	1–10
High	10–100

Image Gently®



- Increase awareness for need to decrease radiation dose to children during CT scans
- Down-size adult CT protocols to kids size
- Consider eliminating multi-phase scans

Image Wisely®

- Increase awareness for need to decrease radiation dose even in adult protocols

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

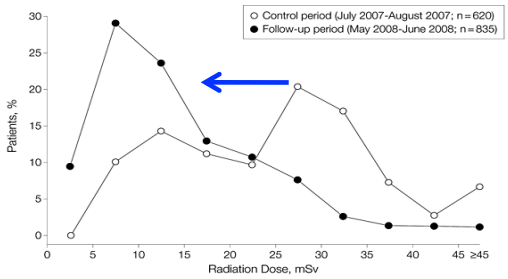
CT Dose Check*

- "Radiation dose check feature will provide an alert to CT machine operators when recommendation radiation levels as determined by users are exceeded"
- Feature expected to be available for new CT scanner soon
- $CTDI_{vol}$ and DLP values can be set for each scan series so that when values exceeds set levels, program will alert operator and if he/she still wishes to continue with the changes then he/she needs to document the reasons
- Program will have capability to track changes that can be audited later

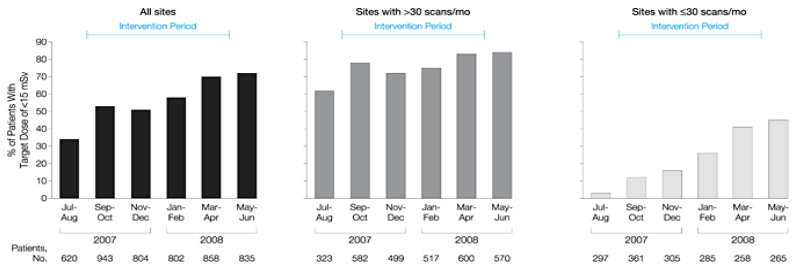
* NEMA XR 25-2010

Impact after implementing radiation reduction techniques

Distribution of Patients by Estimated Radiation Dose



Percentage of Patients Achieving Target Dose of Less Than 15 mSv by Bimonthly Intervals



Raff, G. L. et al. JAMA 2009;301:2340-2348.

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Optimization in Clinical Practice

Recommendation
Individual sites should consider developing site-specific algorithms for radiation dose optimization, which should be reviewed and revised if needed at least annually.

JCCT, 5: 198-224, 2011

Conclusions

- Radiation dose from CT is of concern and has been in the limelight recently
- Optimization of CT protocols are key
- New methods – both technological and practice methods are leading the efforts to reduce CT dose
- Dose reporting is becoming front and center
- Understanding radiation issues and justifying appropriateness of medical x-ray imaging is critical

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD

Benefits of diagnostic radiation outweigh the dangers

But experts recommend having a CT scan or X-ray only 'if there's a good medical reason' for it.

Radiation (Jose J. Santos / Los Angeles Times)

mmahesh@jhmi.edu
Johns Hopkins University, Baltimore, MD