Radiation Dose Optimization Strategies in CT

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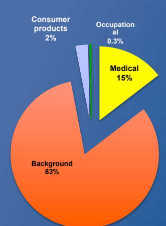
What should we do to reduce radiation risks?

- Explore using Ultrasound and MRI prior to ordering CT
- Ensure CT exam is absolutely necessary and benefits outweigh risks always
  - Avoid repeat studies
  - Minimize multi-phase studies
  - Decrease frequency of follow-up imaging
- Coordinate efforts with radiation oncologists, radiologists, medical physicists and technologists to optimize modalities and protocols to minimize radiation exposure

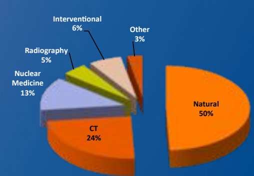
Radiation exposure to US population

US 1982 (NCRP 93)



Medical 0.54 mSv per capita
Total 3.6 mSv per capita

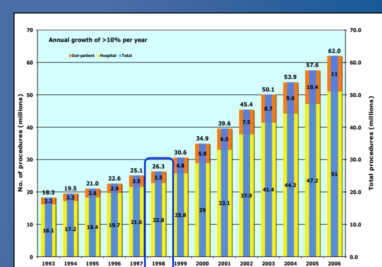
US 2006 (NCRP 160)



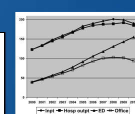
Medical 3.0 mSv per capita
Total 6.2 mSv per capita

NCRP 160 published March 2009

Number of CT procedures in US



MDCT



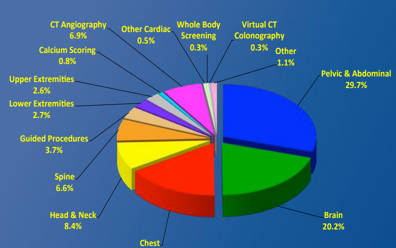
JACR 2012

2007: 68.7 million
2008: 73.1 million
2009: 77.5 million
2010: 81.9 million
2011: 85.3 million
2012: 80.6 million
2013: 76.0 million

IMV Benchmark Reports on CT

Categories of CT procedures

(62.0 million in 2006)



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HCAP: ~80% of all CT procedures

IMV Report, 2006

Effective Doses for Various CT Procedures

Examination	Effective dose (mSv)	Range in literature (mSv)
Adult		
Head	2	0.9 – 4.0
Neck	3	…
Chest	7	4.0 – 18.0
Abdomen	8	3.5 – 25
Pelvis	6	3.3 – 10
Pediatric		
Pediatric Head CT	~3	1.9 - 3.7
Pediatric Chest CT	~3	1.8 – 5.5
Pediatric Abdomen CT	~5	5.0 – 15

Mettler FA, et al., Radiology, 248(1), 254-263, 2008
Pediatr Radiol, 41 (Suppl 2): S493-S497, 2011

Radiation Dose Reduction Strategies

- Optimal tube current selection
  - Dose modulation strategies
- Reduce tube voltage in suitable patients
- Iterative Reconstruction
- Minimize scan range
- Technological advances

Scan Parameters and Image Quality in CT

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
- Patient Motion
- Geometry and Detector Efficiency
- Training and experience

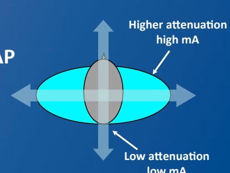
Tube Current (mA)

- Amount of x-rays produced in x-ray tube
- Indicate 'Quantity of x-rays'
- Radiation dose varies linearly with mA
- Decreasing tube current by 50%
  - Decreases radiation dose by ½
  - Increases image noise by √2

CT Dose Modulation

CT dose reductions with tube current modulation

- X-ray attenuation lower in AP and higher in lateral projection

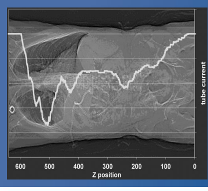


- However, CT doses are uniform on the surface and decreases radially towards center
- Various dose reduction options are possible

Automatic Tube Current Modulation (ATCM)

- Spatial modulation: Based on modulating tube current (mA) at different spatial projections
- Utilized in most routine body CT protocols
- Temporal modulation: Based on modulating tube current (mA) at specified time points of an electrocardiographically gated (ECG) signal
- Utilized in cardiac CT protocols

Dose modulation in z-direction



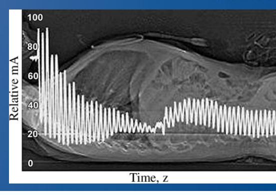


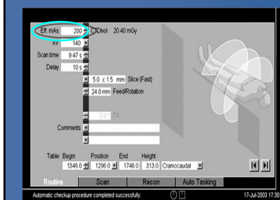
Table 1. AEC techniques currently available from different vendors

AEC Technique	GE Healthcare	Siemens	Philips	Toshiba
x-y axis/angular	Smart mA	CARE Dose	D-DOM	—
z axis/longitudinal	Auto mA	ZEC	Z-DOM	SureExposure
x-y-z/combined	Auto mA 3D	CARE Dose 4D	—	SureExposure3D

Note: AEC = automatic exposure control.

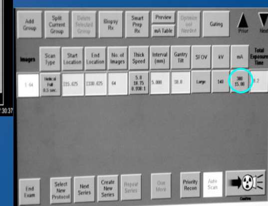
McCollough, C. H. et al. Radiographics 2006;26:503-512

Automatic Exposure Control (AEC)



'Reference Effective mAs'
Siemens

'Noise Index'
GE



How effective is dose modulation?

- Dose modulations is effective for most adult and pediatric protocols
- Studies have shown to reduce radiation dose
  - Chest CT - 14% to 38%
  - Abdominal CT – 20% to 35%
  - Head CT - ~35%

Singh S, et al. JACR, 2011

Temporal Dose Modulation

- Constant tube current through entire R-R cycle can be modulated
- Tube current is lowered outside diastolic region enabling dose reduction during cardiac CT

Shuman, W. P. et al. Radiology 2008

Caveats and Limitations of AEC

- Patient centering is key – specially for Pediatric subjects
- Obese patients
  - AEC techniques increases dose to maintain constant image quality
  - If low contrast detectability is not required, increase may be unnecessary

To modulate dose or not in certain patients?

Scan date: 6-25-2012
Scan without dose modulation
Manual tube current: 300 eff mAs
$CTDI_{vol}$ (ave): 20.14 mGy
DLP: 626 mGy-cm

Scan date: 10-11-2010
Scan with dose modulation
Tube current (eff mAs): 748/200 ref
$CTDI_{vol}$ (ave): 50.50 mGy
DLP: 1412 mGy-cm

JACR, 57: 2477-2490, 2012

Caveats and Limitations of AEC

- Patients with prosthesis
- For very low dose CT protocols (screening) – manual selection of low mA may be advantageous and easier to implement
- Users should be familiar with limitations of AEC techniques

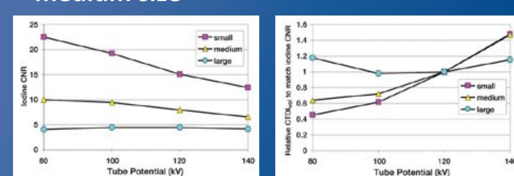
Tube Potential Selection

Tube Voltage (kV)

- Potential difference between anode and cathode of x-ray tube
- Quality of x-rays - affects image contrast
- 120 kV – most common
  - Others – 140/135, 100/110, 80 and even 70 kV
  - 100 kV or 80 kV – thin patients
- CTDI increases with tube voltage (kV^2)

Tube Voltage Modulation

- Lower tube voltage improves image contrast and reduce dose for small and medium size



Radiology 2012; 264(2): :567-580

Iterative Reconstruction

Iterative Reconstruction

- Objective is to enable user to acquire CT data at dose and improve image quality with iterative process
- Most iterative reconstruction algorithms due to manufacturer proprietaries act as 'BLACK BOX'

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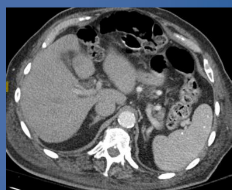
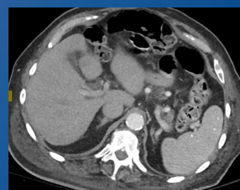
Abdominal CT:
Filtered Back Projection (FBP) vs Iterative Reconstruction

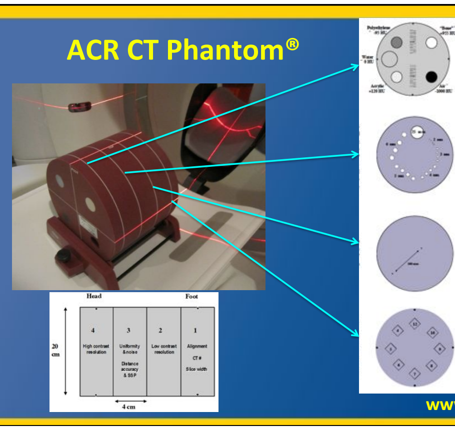


- Standard FBP yielded relatively noisy image



- SAFIRE® – Iterative reconstruction
- Less Noisy

ACR CT Phantom®



www.acr.org

Contrast to Noise Ratio (CNR)

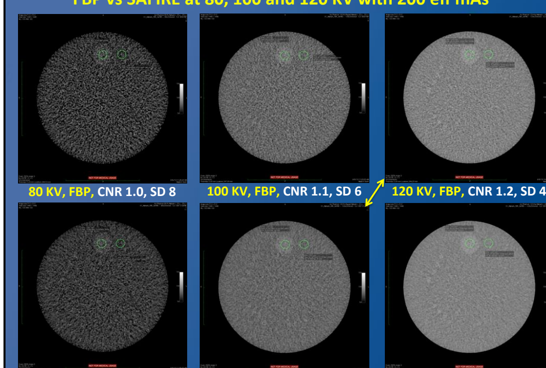
Tube Voltage 120 KV vs 100 KV

- CNR improves with SAFIRE at each tube voltage
- Compared to 120 KV FBP images, CNR increased by 25% for 100 KV images with SAFIRE 3, at the same time radiation dose decreased by 40%

	CNR		
	120 KV	100 KV	%Diff (120 vs 100 kV) FBP vs SAFIRE
	AEC	AEC	
CTDIvol (mGy)	9.2	5.53	-40%
FBP	0.74	0.68	-9%
Safire-1	0.78	0.71	-4%
Safire-2	0.9	0.85	13%
Safire-3	1.07	0.99	25%
Safire-4	1.35	1.1	33%
Safire-5	1.74	1.37	46%

120 KV FBP vs 100 KV SAFIRE 3
40% dose reduction
25% higher CNR

FBP vs SAFIRE at 80, 100 and 120 KV with 200 eff mAs

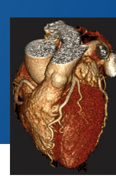


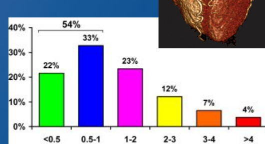
80 KV, FBP, CNR 1.0, SD 8 | 100 KV, FBP, CNR 1.1, SD 6 | 120 KV, FBP, CNR 1.2, SD 4

80 KV, SAFIRE 3, CNR 1.3, SD 5 | 100 KV, SAFIRE 3, CNR 1.5, SD 4 | 120KV, SAFIRE 3, CNR 2.3, SD 3

Cardiac CTA – submSv studies

- 107 patients
  - 27.3 BMI
  - 100 kVp for 97 patients
- Wide volume coverage (320 * 0.5 mm - Toshiba 320)
- Iterative Reconstruction
- Automatic exposure control
- Radiation dose – 0.93 mSv (0.58 – 1.74 mSv)





Chen MY, et al., Radiology 2013

Other initiatives aimed at reducing dose

- Adopting appropriateness criteria into physician decision making
- Increased awareness
  - Such as *Image Gently® and Image Wisely®* campaign
  - Education and Radiation awareness

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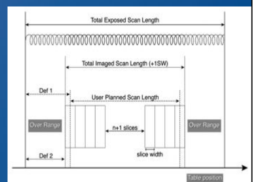
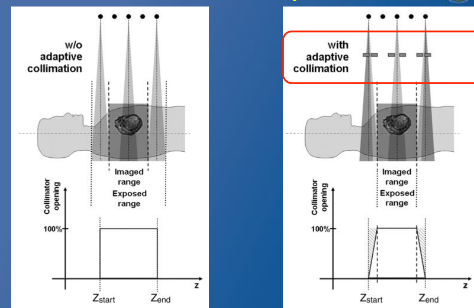
Over-ranging in MDCT

- 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

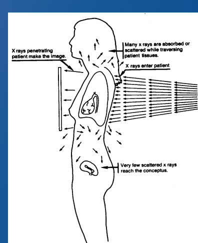
Conventional and Adaptive Collimation



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

CT & Fetal Irradiation

- Fetus not directly in the x-ray beam as in Chest CT or Head CT
- Very few scattered x-rays reach fetus
- Mostly Internal scatter



Wagner LK, Lester RG and Saldana LR. Exposure of the Pregnant Patient to Diagnostic Radiations. Medical Physics Publishing, Madison, WI, 1997

Organ or Tissue Weighting Factors (w_T)

Organ or Tissue	Weighting factor* ICRP 60	ICRP 103
Breast	0.05	0.12
Red bone marrow, Colon, Lung, Stomach	0.12	0.12
Remainder[†] tissues	0.12	0.12
Gonads	0.20	0.08
Bladder, Liver, Thyroid & Esophagus	0.05	0.04
Skin & Bone surface	0.01	0.01
Brain & Salivary glands		0.01

[†]Accounts additional tissues/organs such as adernals, kidney, small and large intestine, muscle, pancreas, spleen, thymus and uterus

* ICRP 103, 2007

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

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