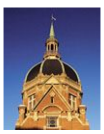
52nd Annual Meeting July 18-22, 2010 Pennsylvania Convention Center Philadelphia, Pennsylvania

New Technologies for Image Quality Improvement and Dose Reduction in CT

Mahadevappa Mahesh, MS, PhD, FAAPM, FACR.

Associate Professor of Radiology & Cardiology

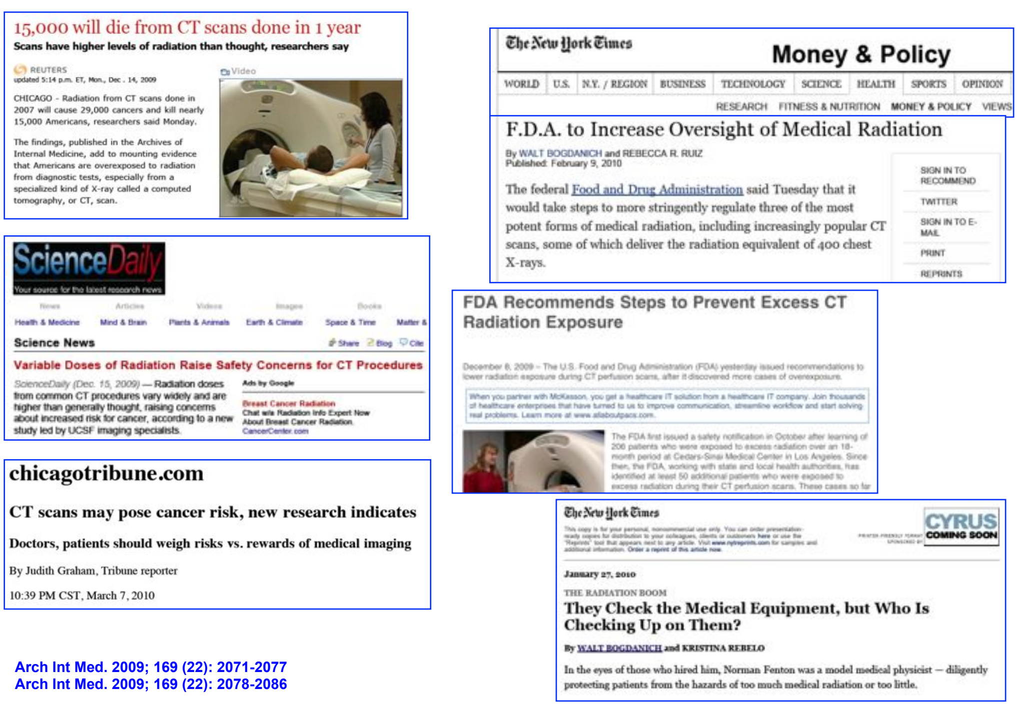
Chief Physicist - Johns Hopkins Hospital



The Russell H. Morgan Department of Radiology and Radiological Science

Johns Hopkins University, Baltimore, MD

52nd Annual AAPM Meeting, Philadelphia, PA. July 20th, 2010



15,000 will die from CT scans done in 1 year

Scans have higher levels of radiation than thought, researchers say

REUTERS
updated 5:14 p.m. ET, Mon., Dec. 14, 2009

CHICAGO - Radiation from CT scans done in 2007 will cause 29,000 cancers and kill nearly 15,000 Americans, researchers said Monday.

The findings, published in the Archives of Internal Medicine, add to mounting evidence that Americans are overexposed to radiation from diagnostic tests, especially from a specialized kind of X-ray called a computed tomography, or CT, scan.

ScienceDaily

Science News

Variable Doses of Radiation Raise Safety Concerns for CT Procedures

ScienceDaily (Dec. 15, 2009) — Radiation doses from common CT procedures vary widely and are higher than generally thought, raising concerns about increased risk for cancer, according to a new study led by UCSF imaging specialists.

chicagotribune.com

CT scans may pose cancer risk, new research indicates

Doctors, patients should weigh risks vs. rewards of medical imaging

By Judith Graham, Tribune reporter

10:39 PM CST, March 7, 2010

The New York Times — Money & Policy

F.D.A. to Increase Oversight of Medical Radiation

By WALT BOGDANICH and REBECCA R. RUIZ
Published: February 9, 2010

The federal Food and Drug Administration said Tuesday that it would take steps to more stringently regulate three of the most potent forms of medical radiation, including increasingly popular CT scans, some of which deliver the radiation equivalent of 400 chest X-rays.

FDA Recommends Steps to Prevent Excess CT Radiation Exposure

The New York Times

January 27, 2010

THE RADIATION BOOM

They Check the Medical Equipment, but Who Is Checking Up on Them?

By WALT BOGDANICH and KRISTINA REBELO

In the eyes of those who hired him, Norman Fenton was a model medical physicist — diligently protecting patients from the hazards of too much medical radiation or too little.

Arch Int Med. 2009; 169 (22): 2071-2077
Arch Int Med. 2009; 169 (22): 2078-2086

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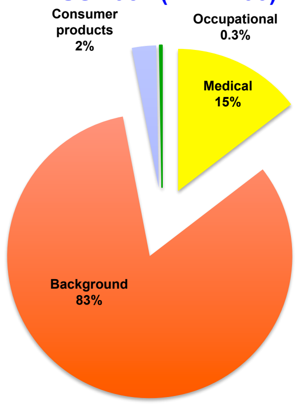
Radiation exposure to US population from all sources

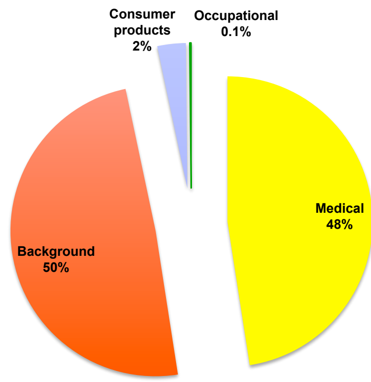
The new pie chart!

US 1982 (NCRP 93)



Medical 0.54 mSv per capita
Total 3.6 mSv per capita

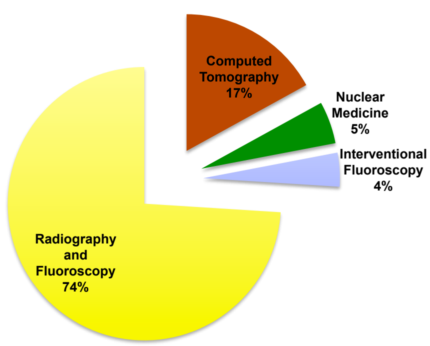
US 2006



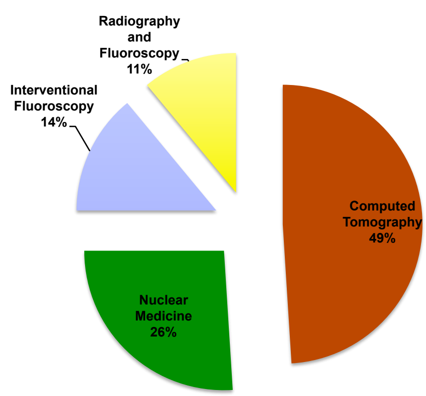
Medical 3.0 mSv per capita
Total 6.2 mSv per capita

NCRP 160 published March 2009

NCRP 160: Medical Exposure
Procedures vs Effective dose contributions



Percent Procedures



Effective Dose Contributions

Effective dose per capita from medical radiation exposure is ~3.0 mSv

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Estimated number and collective doses from various medical imaging categories using ionizing radiation*

Modalities	Number Procedures (millions)	%	Collective dose (Person-Sv)	%	Per capita (mSv)
CT	67[a]	17	440,000	49	1.50
Nuclear Medicine	18	5	231,000	26	0.80
Interventional	17	4	128,000	14	0.40
Radiography & Fluoroscopy[b]	293	74	100,000	11	0.30
Total	~395		899,000		~3.0

26% (CT + Nuclear Medicine + Interventional, % of procedures)

89% (CT + Nuclear Medicine + Interventional, % of collective dose)

[a] Number of CT scans
[b] Excludes dental bitewing and full mouth procedures, but includes 2500 person –Sv for collective dose

NCRP 160

Computed Tomography (CT)

- Annual growth over 1993-2006:
  - CT Procedures > 10% vs US population < 1%
- Nearly 62 million CT procedures in US in 2006
- Data correlated to nearly 7649 hospitals in US
- Pediatric CT ~8-10% of total procedures

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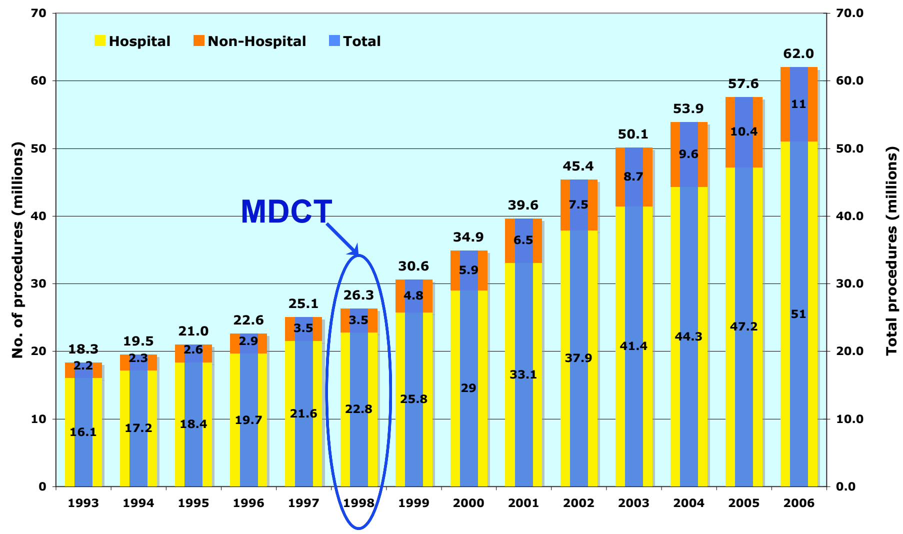
Number of CT procedures in US



IMV Benchmark Reports on CT

2007: 68.7 million CT

Collective doses for CT (2006)

	Number (millions)	%	Effective dose per scan (mSv)	Collective dose Person-Sv	%
Head	19.0	28	2	38,000	8.7
Chest	10.6	16	7	74,000	17.0
Abd/Pelvis	25.4	39	10	254,000	58.0
Extremity	3.5	5	0.1	500	0.1
CT Angiogram	4.3	6	5 (Head) 20 (Cardiac)	56,000	12.8
Miscellaneous	4.2	6		15,000	3.4
TOTAL	67			438,000	

84%

HCAP: 83%

NCRP Report 160

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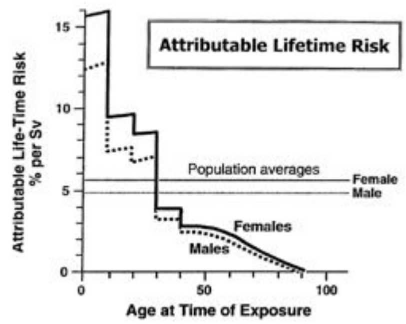
Cancer Risks

- Average risk for radiation induced cancer in general population is 5% per Sv
- Children are 2-3 times at higher risk than adults (as high as 15% per Sv)
- For persons aged > 50 years risk is 1/5th to 1/10th of that for younger adults



1 Sv = 100 rem
10 mSv = 1 rem

Hall EJ, Ped Radiol, 2002

Deterministic Effects - Rare but possible in CT

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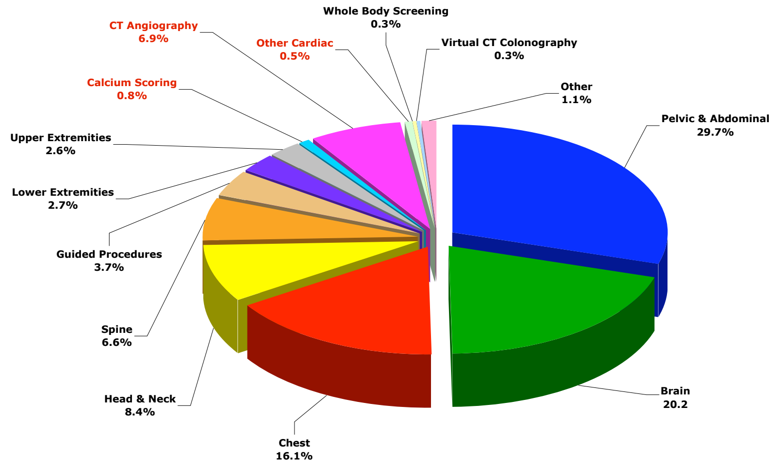
Categories of CT procedures

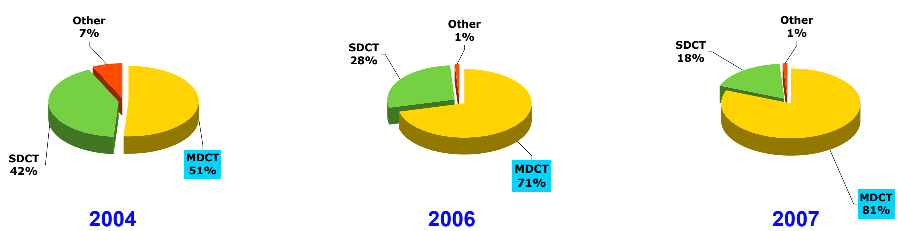
(62.0 million in 2006)



HCAP: ~80% of all CT procedures

IMV Report, 2006

MDCT growth in US as percent CT scanners in clinical use



Survey Year	2004	2006	2007
Total CT installed in US	9,380	10,110	10,300
MDCT	51%	71%	81%
SDCT	42%	28%	18%
Other	7%	1%	1 %

Mahesh M, MDCT: The Basics …, Lippincott, 2009

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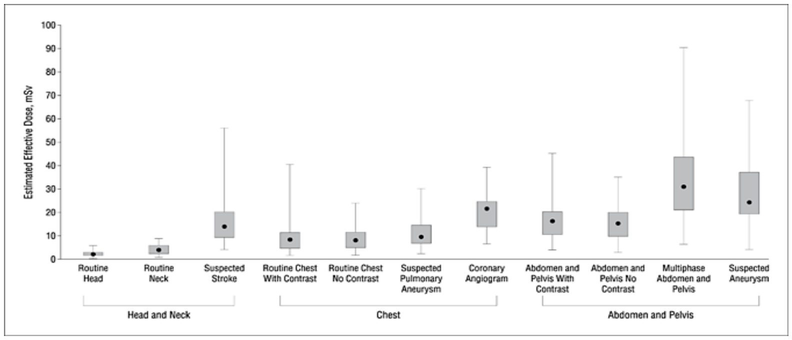
Distribution of median (interquartile range) estimated effective dose by computed tomography study type

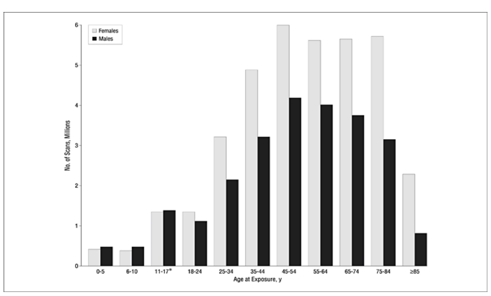


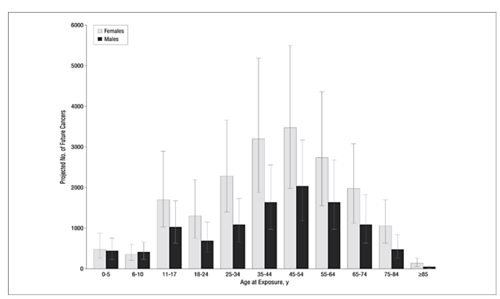
Effective dose for CT procedure varied within and across institutions with a mean 13-fold variation between highest and lowest dose for each study type

Smith-Bindman, R, … Mahesh M, et al. Arch Intern Med 2009;169:2078-2086.

ARCHIVES OF INTERNAL MEDICINE

CT scans and associated Risks





Estimated number CT scans performed in the United States in 2007 according to sex and age at exposure

Projected number of future that could be related to CT scan use in the United States in 2007, according to age at exposure

Berrington de Gonzalez, A, Mahesh M, et al. Arch Intern Med 2009;169:2071-2077.

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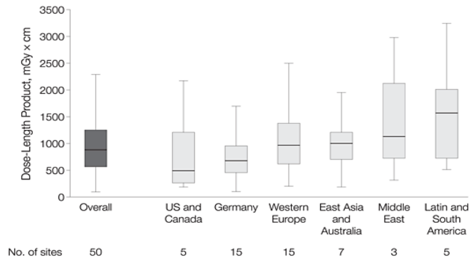
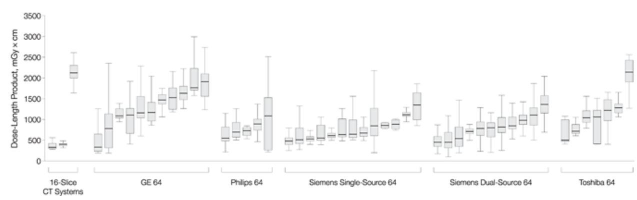
Overall and World Regional Radiation Dose of Cardiac Computed Tomography Angiographies



Site-Specific and System-Specific Radiation Dose of Cardiac Computed Tomography Angiographies for the 50 Participating Study Sites



Hausleiter, J. et al. JAMA 2009;301:500-507.

JAMA

Probable causes for increase in medical exposures

- Advances in medical technology
- Demand of improved patient care
- Easy to use -
  - Out of the box solution, for ex: CT
- Accessibility
  - Emergency Rooms - Outpatient - Doctor's offices - …

- Overall Benefits outweighs Risks!

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Radiation Dose Reduction Strategies

- Optimal tube current (mA) selection
  - Dose modulation strategies
- Reduce tube voltage in suitable patients
- Minimize scan range
- Heart rate reduction
- ECG gated tube current modulation
- Sequential Scanning
- Perform calcium scoring only if needed
- Iterative Reconstruction…

CT Dose Modulation

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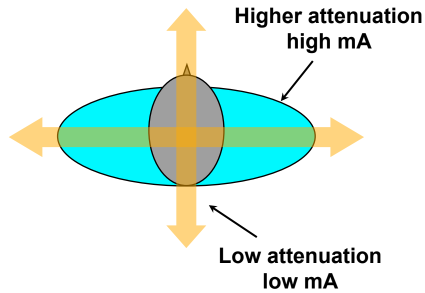
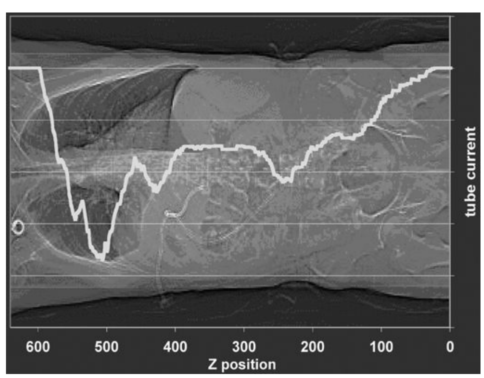
CT dose reductions with tube current modulation



- 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 been considered

Dose modulation in z-direction



- Graph of tube current superimposed on a CT projection radiograph to illustrate longitudinal dose modulation concept, with variation of the tube current along the z-axis

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

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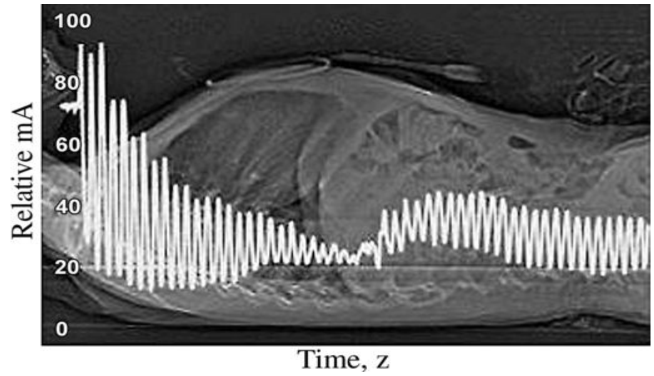
Dose modulation in z-direction



- **Tube current as function of time (hence table position) during spiral CT of 6 year child**

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

Cardiac CT Imaging

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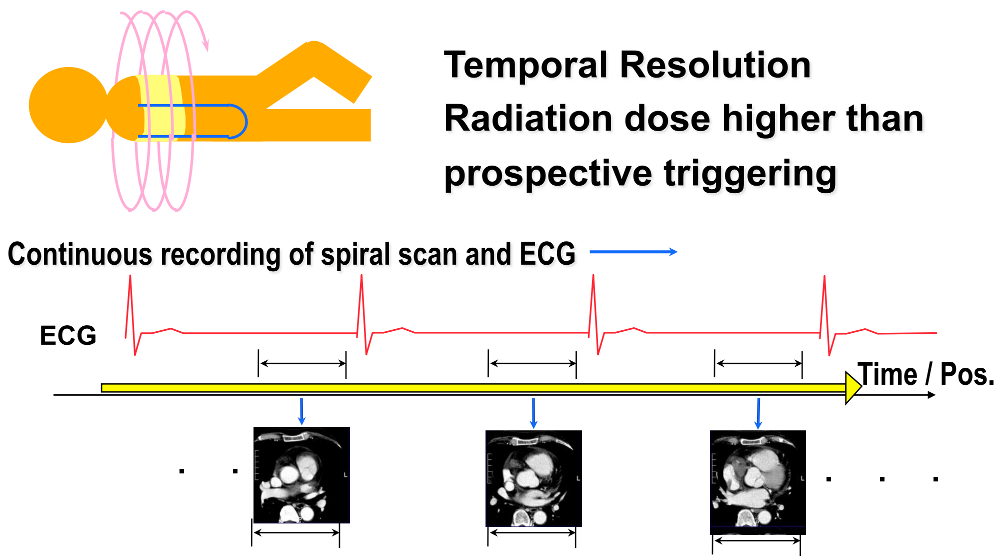
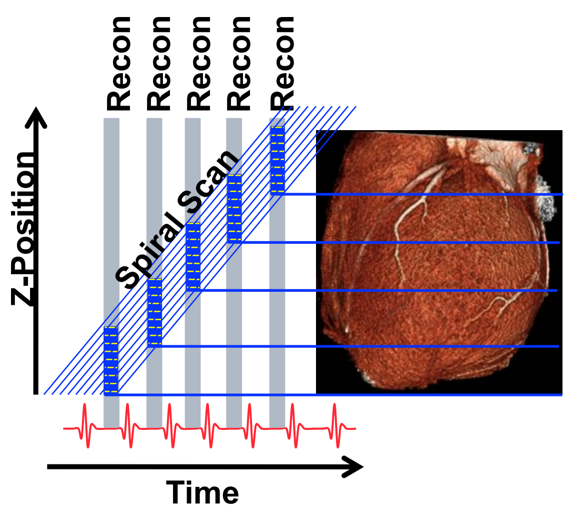
Retrospective ECG Gating



Retrospective ECG Gating



N*T: 64*0.625 – 40 mm scan coverage

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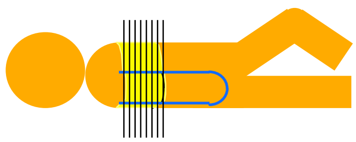
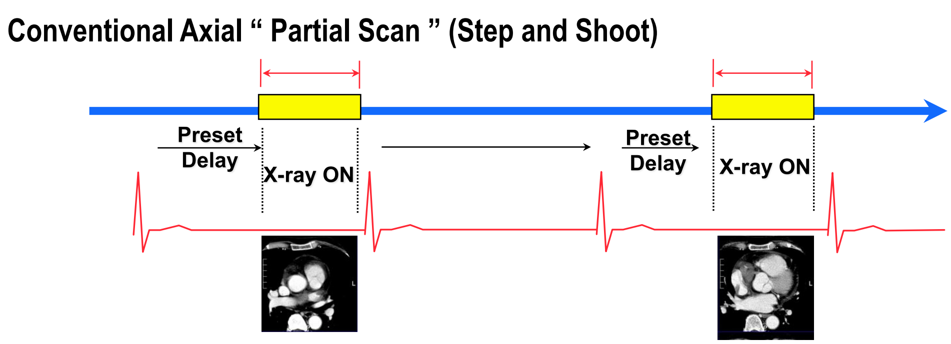
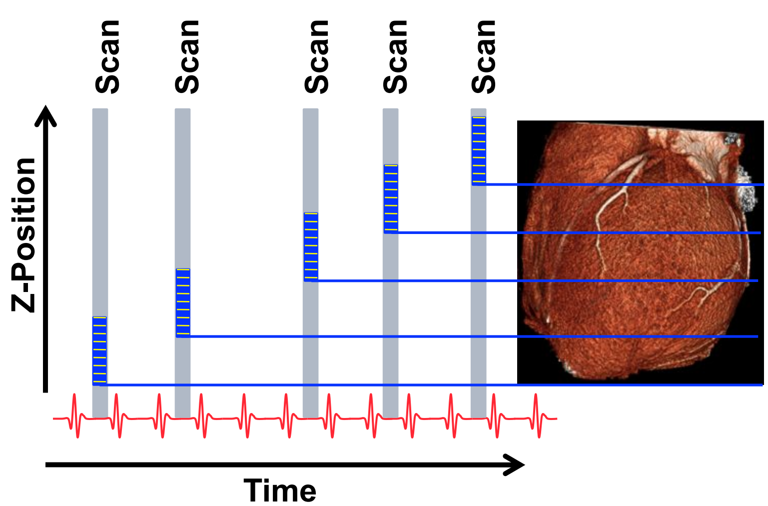
Prospective ECG Triggering



Temporal resolution
Radiation dose minimized
Limited data set



Prospective ECG Triggering



N*T: 64*0.625 – 40 mm scan coverage

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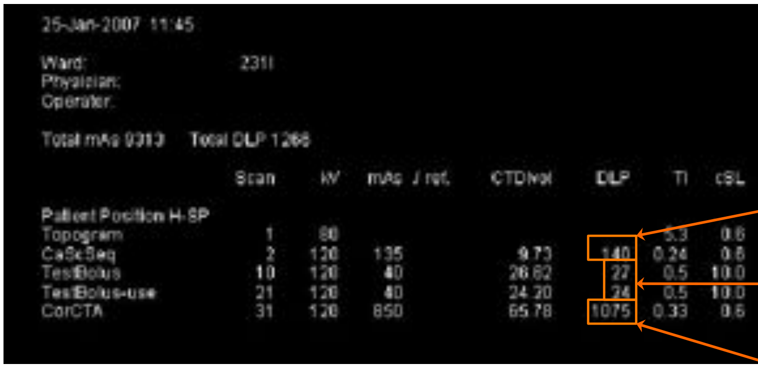
Radiation Dose Report - CT Angiography Exam



25-Jan-2007 11:45

Ward: 2311
Physician:
Operator:

Total mAs 9313 Total DLP 1266

	Scan	kV	mAs / ref.	CTDIvol	DLP	TI	cSL
Patient Position H-SP							
Topogram	1	80				5.3	0.6
CaScSeq	2	120	135	9.73	140	0.24	0.6
TestBolus	10	120	40	26.62	27	0.5	10.0
TestBolus-use	21	120	40	24.20	24	0.5	10.0
CorCTA	31	120	850	65.78	1075	0.33	0.6

Effective dose (mSv)

2.0 mSv

0.7 mSv

15.0 mSv

Total effective dose (mSv) 17.7 mSv

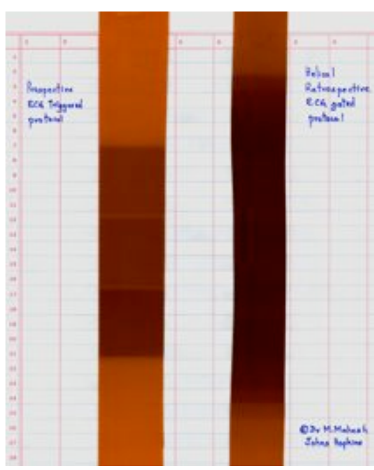
k = 0.014 mSv/mGy.cm

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

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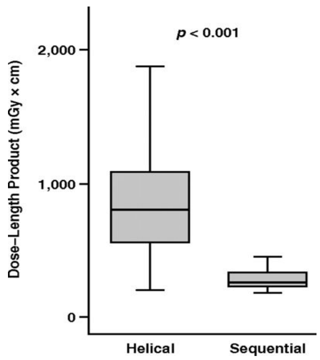
Radiation Dose and Image Quality Comparison for Helical Vs Sequential Cardiac CT Scan



Radiation Dose

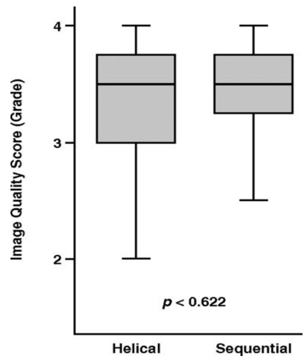


Image Quality

Bischoff, B. et al. Am. J. Roentgenol. 2010;194:1495-1499

Wide detector (320 row) MDCT

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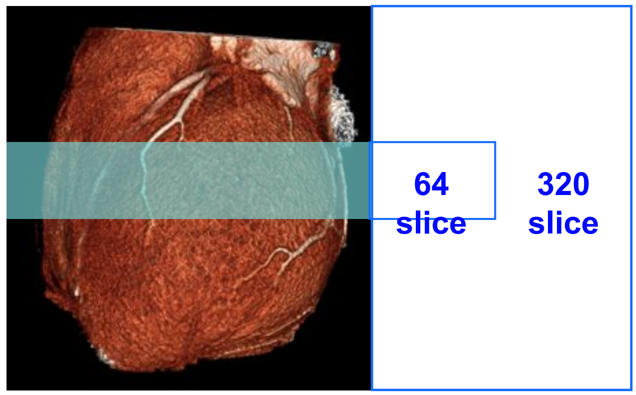
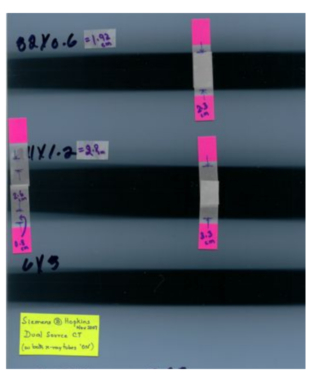
Scan coverage - 320 vs 64 slice MDCT



Toshiba
Aquillion 64 - 32 mm beam width
Aquillion One - 320 slice MDCT - 160 mm beam width

MDCT Physics: The Basics…, Lippincott, 2009

X-ray beam profiles*: DSCT vs 320 MDCT



Siemens DSCT
(w both tubes ON)

Toshiba 320 row MDCT
(measured at isocenter)

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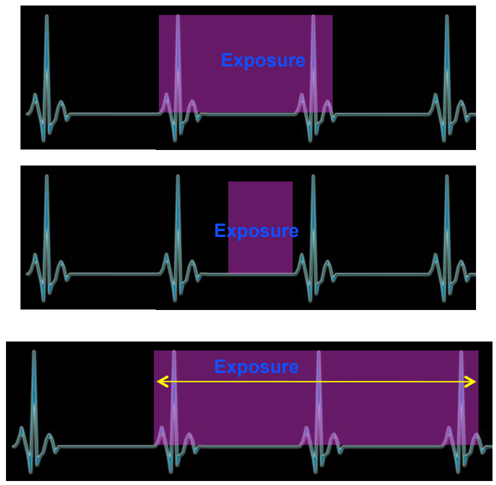
320 MDCT: Cardiac CTA Protocol
Single Heart Beat Protocol (for HR ≤ 65 bpm)

Single Heart Beat Protocol (for HR ≤ 65 bpm)



Without ECG Dose Modulation*

With ECG Dose Modulation

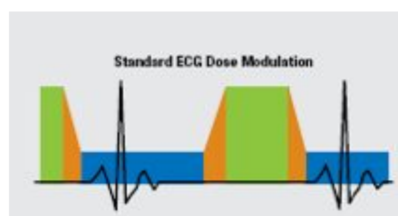
2-Heart Beat Protocol (for HR ≥ 65 bpm)

Without ECG Dose Modulation*

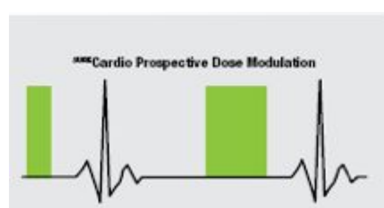
Toshiba

SureCardio Prospective on 320 MDCT scanner

- Ultra low dose cardiac CTA acquired in continuous helical mode
- Extension of dose modulation technique: X-rays turned completely OFF during systole



Standard Modulation: 20% dose reduction



SURECardio Prospective: 80% dose reduction

TOSHIBA
Leading Innovation

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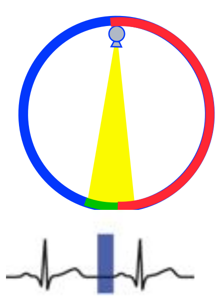
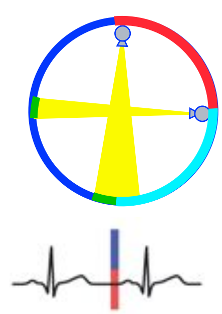
Dual Source CT

Single Source vs Dual Source CT*





64 Slice MDCT ~190 ms

180° Data Acquisition

DSCT ~ 90 ms

90° Data Acquisition per tube

Result: Comparable image quality and spatial resolution

Temporal resolution: ~ $1/3^{rd}$ to $1/4^{th}$ of gantry rotation time

*** Siemens**

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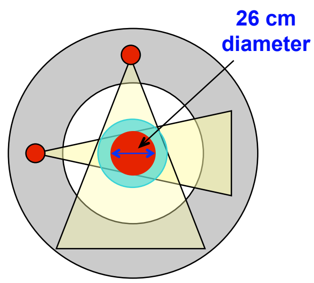
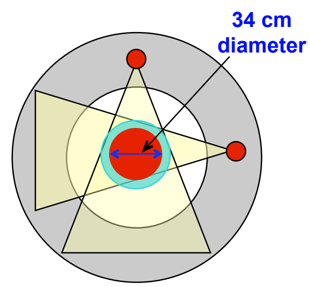
DSCT*: Definition vs Definition FLASH



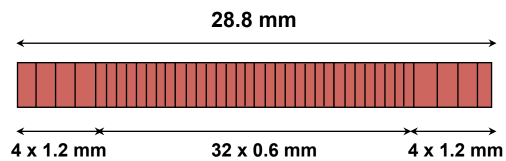


Definition
2nd detector set smaller than 1st
SFOV-1: 50 cm
SFOV-2: 26 cm
Capable of 64 slices
Anatomical coverage per rotation: 28.8 mm

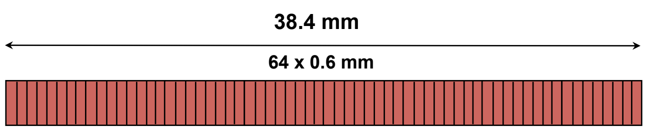
Definition – FLASH
2nd detector set still smaller than 1st
SFOV-1: 50 cm
SFOV-2: 34 cm
Capable of 128 slices
Anatomical coverage per rotation: 38.4 mm

* Siemens

DSCT Detector Configuration: Definition vs Definition FLASH

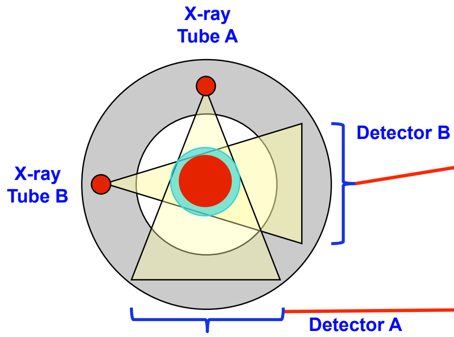


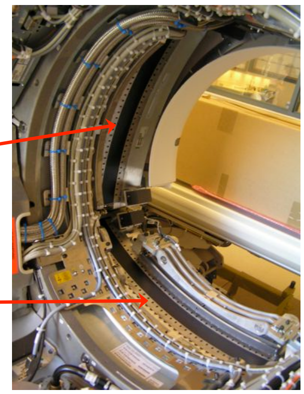
DSCT-Definition



DSCT-Definition - FLASH

Dual Source CT: Definition FLASH*





Definition – FLASH

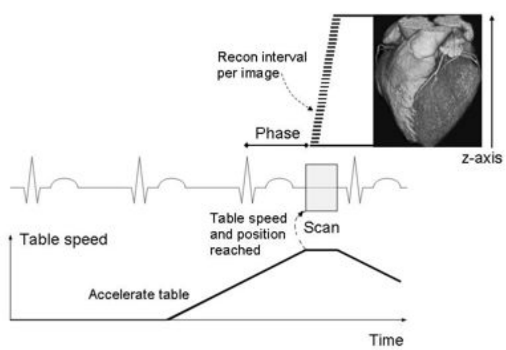
2nd Detector set still smaller than 1st but larger than Definition
SFOV: 1st detector – 50 cm, 2nd detector – 34 cm

*** Siemens**

Johns Hopkins – May 2009

Data Acquisition with *DSCT-Flash*

- **Table speed: 430 mm/s**
- **Pitch: 3.2**
- **Gantry rotation time: 0.28 sec**
- **Beam width: 38.4 mm**
- **Maximum slices: 128**
- **Scan range: 120 mm**
- **Scan time: 280 ms**



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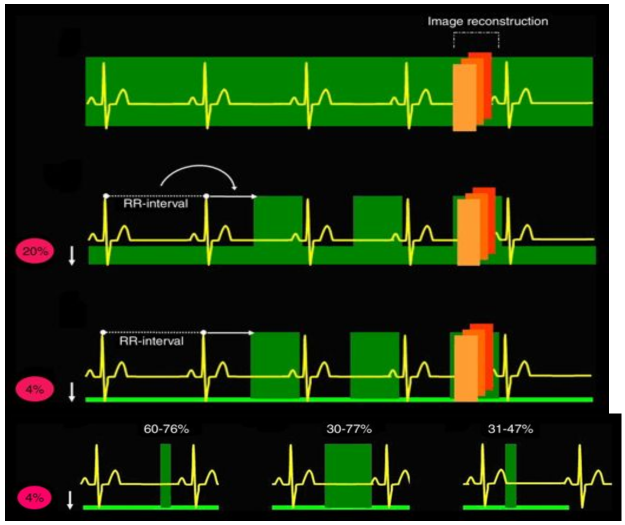
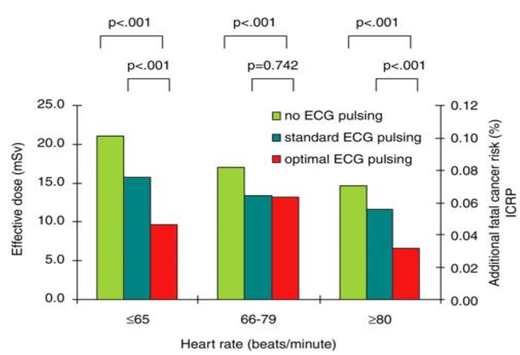
Cardiac CT Imaging with DSCT



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

DSCT: Cardiac Imaging with ECG Pulsing

- **Effective doses and additional fatal cancer risks associated with standard and optimal ECG pulsing versus no ECG pulsing**
- **Dose reduction up to 55% in patient with high heart rates**



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

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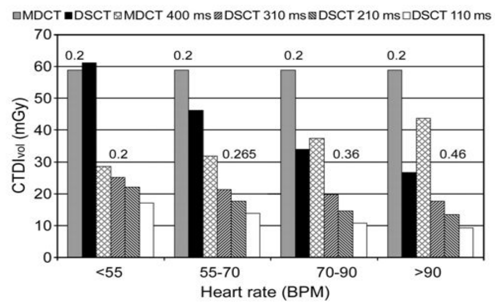
Dose Reduction Opportunities with DSCT

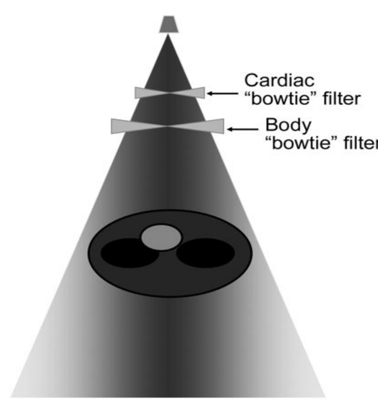
- Cumulative dose reduction for coronary CT angiography obtained by using four dose-reduction mechanisms implemented with dual -source CT (DSCT) system



McCollough, C. H. et al. Radiology 2007;243:775-784

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

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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

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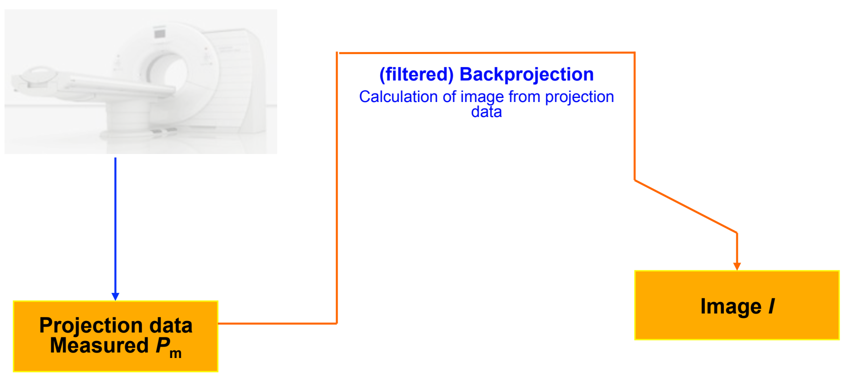
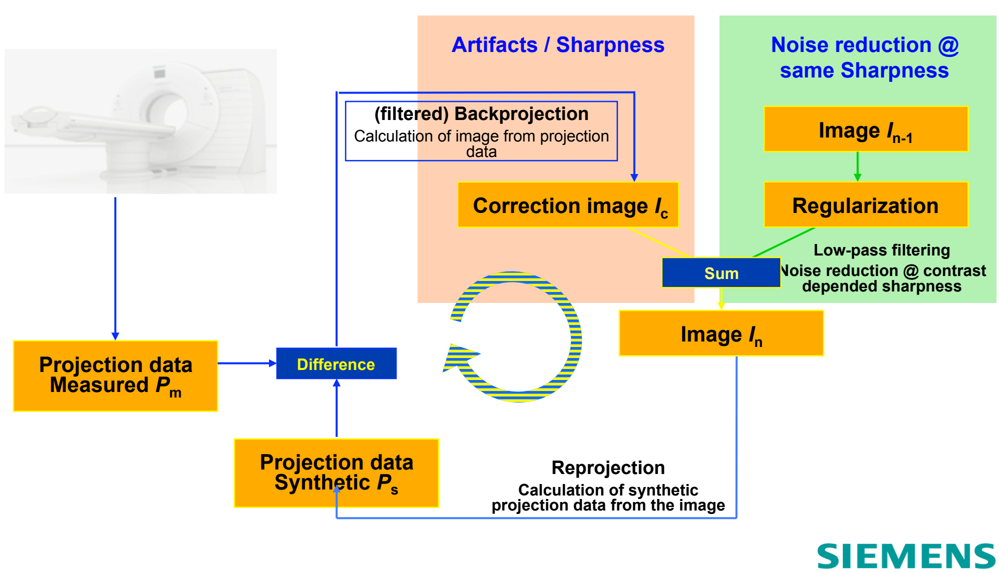
Iterative Reconstruction – Work in Progress



Iterative Reconstruction – Work in Progress



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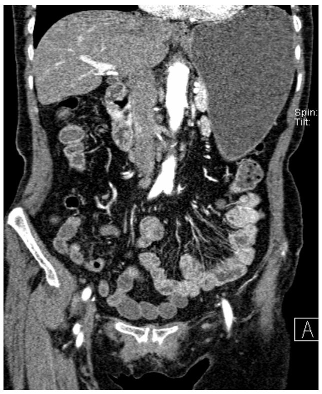
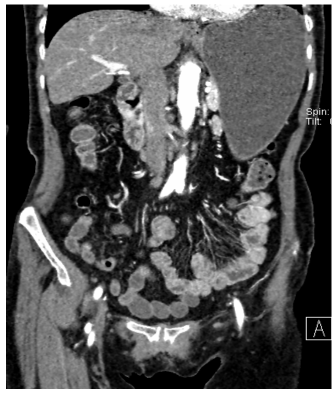
Iterative Reconstruction - Noise Reduction

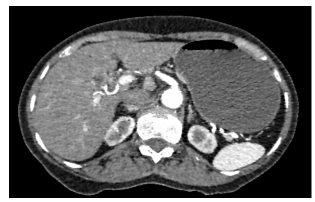


Standard reconstruction



2 Iterations

Standard



2 Iterations

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

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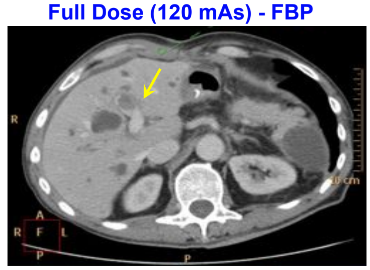
Comparison Full Dose / Dose Reduction 50% + iDose

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.

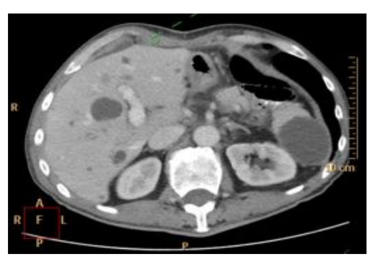
Full Dose (120 mAs) - FBP



Follow up with 50% Dose Reduction

50% Dose (60 mAs) - FBP

iDose



50% Dose (60 mAs) + iDose

Philips

Courtesy Dr Dobritz, TU Munich, Germany

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DECT approaches

- **Dual x-ray tube – each tube set at different kVp**
- **Switching kVp on the fly to obtain dual energy CT data**
- **CT detector in Sandwich form – yielding dual signal for each exposure**
- **Photon counting detector with energy resolving capability**

Further Potential for Dose Reduction

Auto kV – Basic Idea

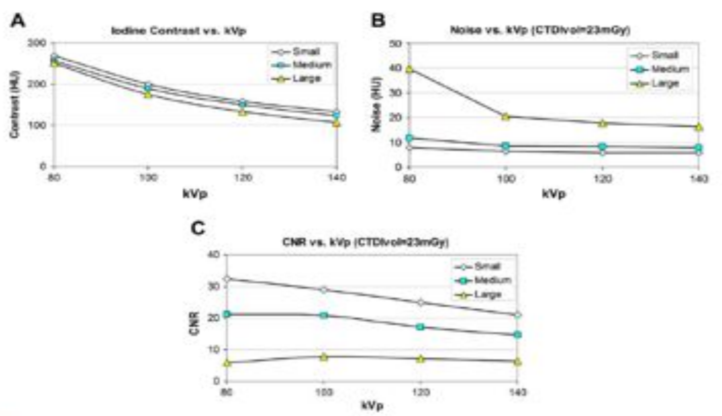

Fig. 3. (*A*) Graph of the CT number of a 2% iodine solution for small, medium, and large phantoms at various x-ray tube potentials. (*B*) Graph of noise (standard deviation of CT numbers within the water background) in images of small, medium, and large phantoms at different tube potentials. (*C*) Graph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

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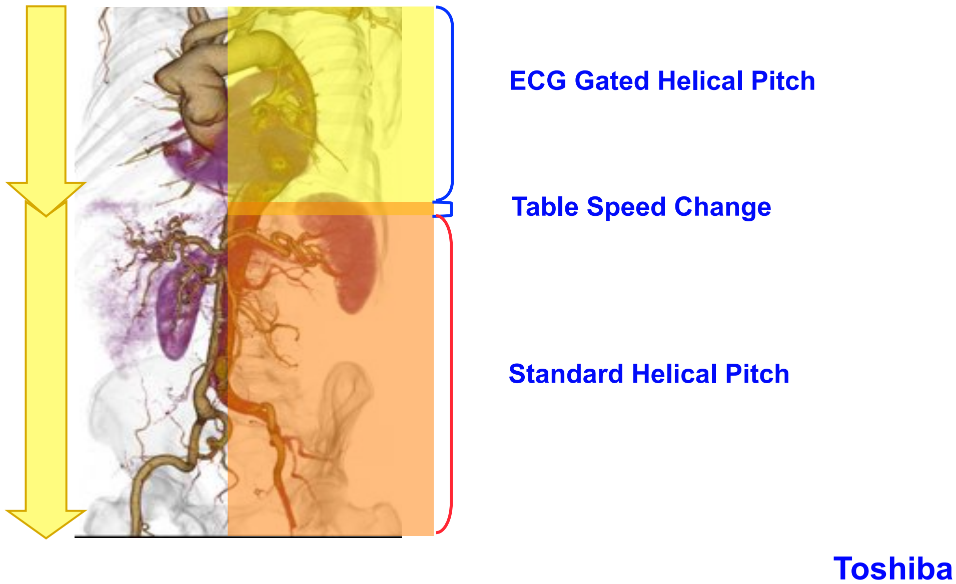
Variable Helical Pitch (vHP)



Multiphasic CT exams

- 3 phase liver study
- Chest CT with and without contrast
- Cardiac CT exam including functional studies that involves CTA + CT Perfusion

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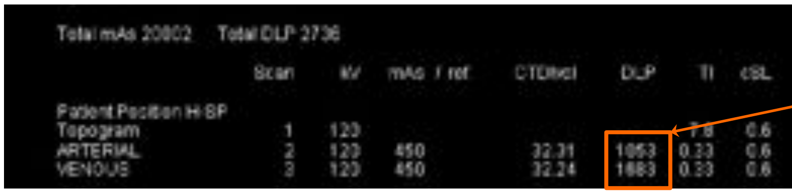
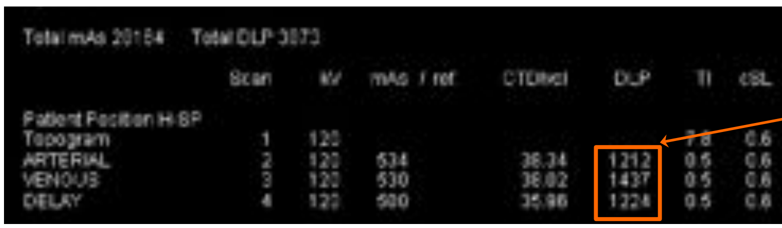
CT exam of abdomen and pelvis: Sample dose reports

Arterial and Venous scan series


Total mAs 20802 Total DLP 2736

	Scan	kV	mAs / ref	CTDIvol	DLP	TI	cSL
Patient Position H-SP							
Topogram	1	120				7.8	0.6
ARTERIAL	2	120	450	32.31	1053	0.33	0.6
VENOUS	3	120	450	32.24	1683	0.33	0.6

Arterial, Venous and Delay scan series


Total mAs 20154 Total DLP 3873

	Scan	kV	mAs / ref	CTDIvol	DLP	TI	cSL
Patient Position H-SP							
Topogram	1	120				7.8	0.6
ARTERIAL	2	120	534	36.34	1212	0.5	0.6
VENOUS	3	120	530	36.02	1437	0.5	0.6
DELAY	4	120	500	35.96	1224	0.5	0.6

k = 0.015 mSv/mGy.cm

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

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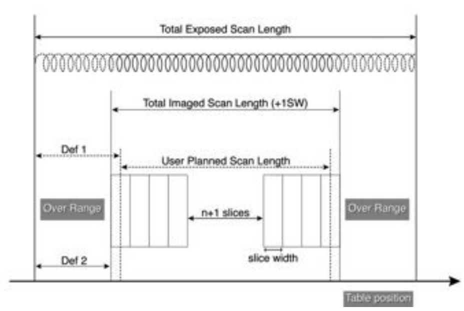
Over-ranging in CT scans

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

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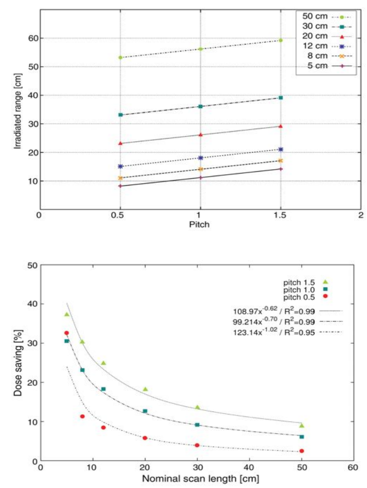
Over-scanning effect with 64 slice MDCT

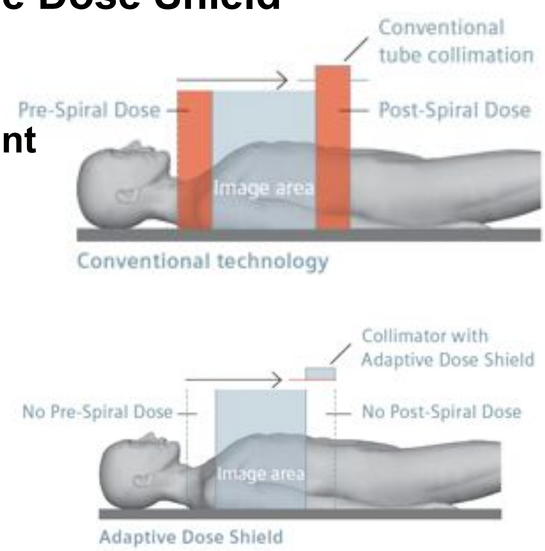
- **Over-scanning increases with pitch**
- **Adaptive shielding can reduce dose by nearly 7% for all scan lengths and can even reduces up to 38% for scan lengths smaller than 12 cm**



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

Adaptive Dose Shield

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



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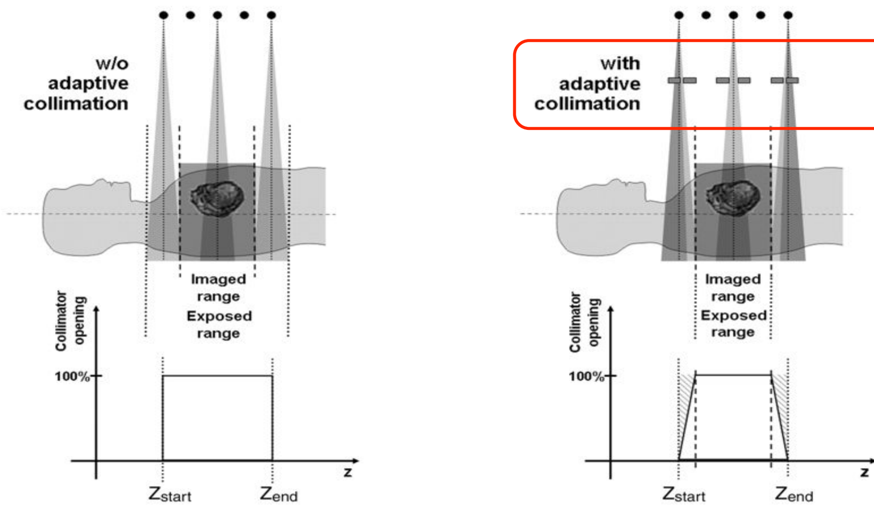
Conventional and Adaptive Collimation



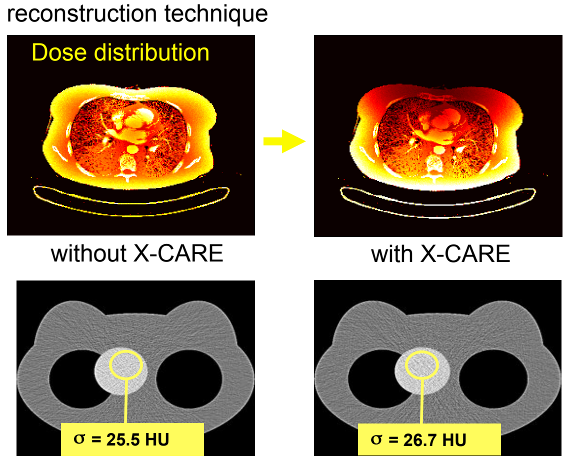
Deak, P. D. et al. Radiology 2009;252:140-147

New Horizons on Dose Saving
Dose reduction with X-CARE to Breast Tissue

SIEMENS

X-CARE: Dose and Image Quality

Organ based dose modulation reduces radiation exposure of the breast by 30-40%
Noise level is maintained with dedicated reconstruction technique



Schmidt et al., Suppl. Radiology, (2003)

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CT Dose – Positive Developments

- **Dose modulation techniques**
- **American College of Radiology**
  - **Relative Radiation Levels**
  - **Appropriateness Criteria**
  - **CT Accreditation program**
- **Increased awareness**
  - **Such as *Image Gently* campaign**
- **Education and Radiation awareness**

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**

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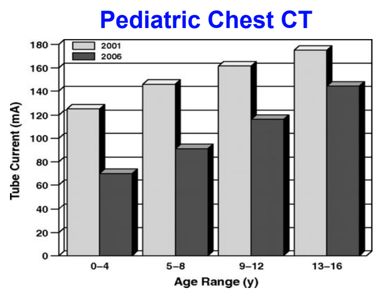
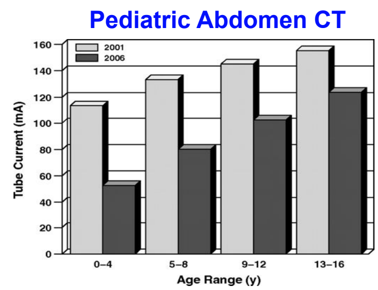
Impact of increase awareness about radiation risks

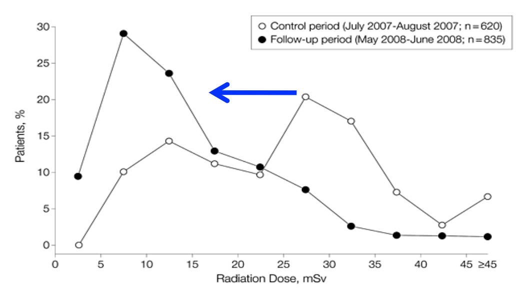




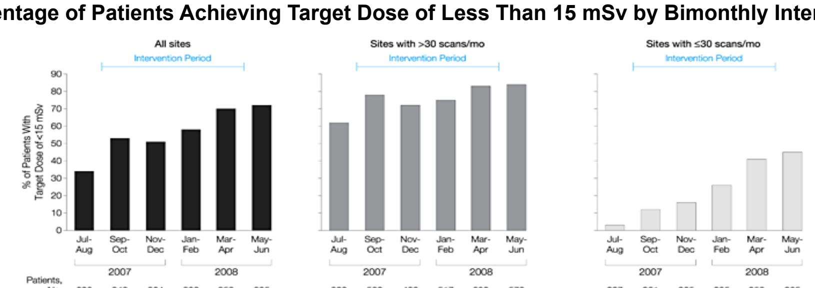
- **5 year follow-up study among members of Society of Pediatric Radiologists**
- **Significant decrease in tube current and tube voltage settings**

Arch, M. E. et al. Am. J. Roentgenol. 2008;191:611-617

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.

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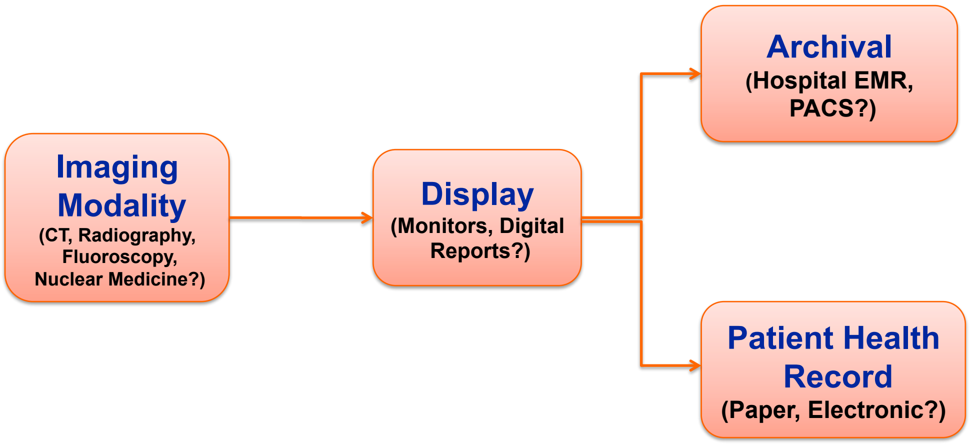
NIH Radiation Dose Reporting Policy

Electronic Reporting of Radiation Exposures from Medical X-ray Imaging Procedures



Key Points

- **Dose modulation – applicable for most adult CT protocols – achieve significant dose reduction**
- **Dose modulation for pediatric CT – need careful selection – correct positioning – selection correct reference mAs**
- **Over-scanning – can be lowered with attention to prescribing the scan region on topograms and also examining new dynamic collimation technologies**

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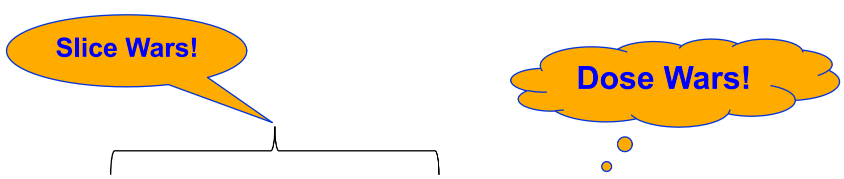
Conclusions

- 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



Past – Present - Future

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