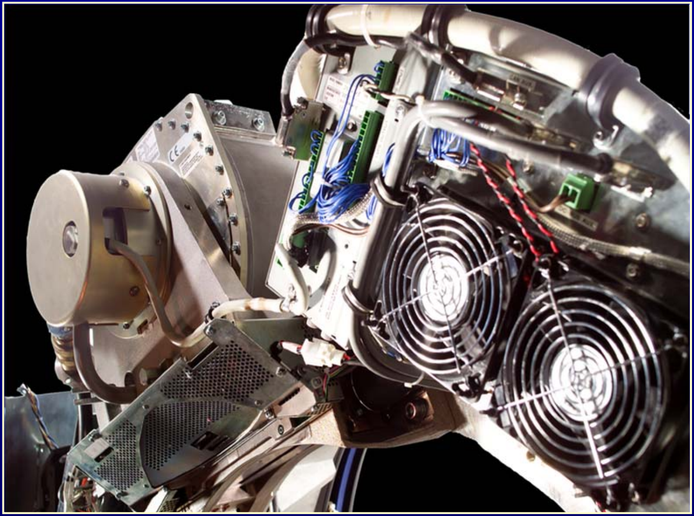
Adapting Scanner Settings To Match Clinical Indication: How Much Variation is Needed

James A. Brink, MD
Yale University School of Medicine

Faster Rotation-->Higher Tube Capacity



Rapid Tube rotation (sec)

High Tube Power (mA)

"Adequate" mAs

Potential for Excessively High Dose

Technique

- Tube Current (mA)
- Tube Voltage (kVp)
- Pitch
- Recon. Algorithm

Outline

- Variation based on body habitus
- Variation based on clinical indication
  - Head / Neck
  - Chest / Cardiac
  - Abdomen / Pelvis
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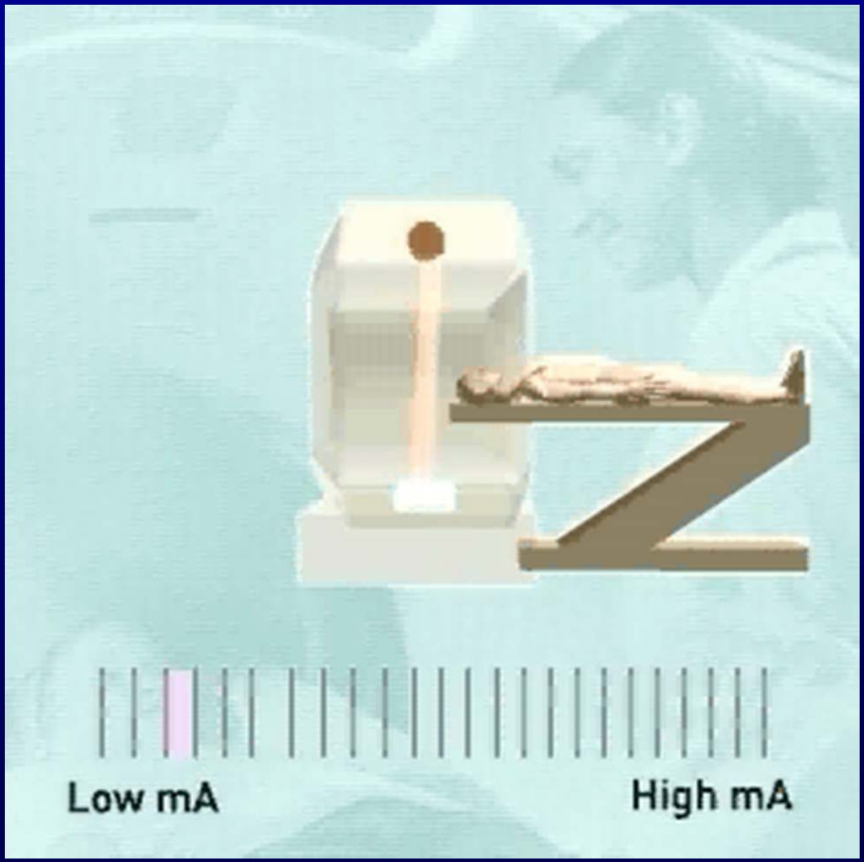
  - Computerized order entry / decision support
  - Integration with EMR

Automatic Tube Current Modulation



Dose reduction of up to 50% (Mulkens TH, et al. Radiology 2005; 237:213-223)

Impact of Patient Weight on ACTM

Patient Size and Radiation Exposure in Thoracic, Pelvic, and Abdominal CT Examinations Performed With Automatic Exposure Control

Gary M. Israel[1]
Lawrence Cicchiello[1]
James Brink[1]
Walter Huda[2]

- 91 pts for Chest, Abdomen, Pelvis CT w/ 64DCT
  - NI=11.5, 5mm, rot=1s, pitch=1, 120kV, mA_{max}=800 mA
- $CTDI_{vol}$ obtained from console + Impact Dose Calculator
  - organ doses computed for a 70kg patient
- Patient doses were calculated by correcting for pt. size

AJR 2010; 195:1342–1346

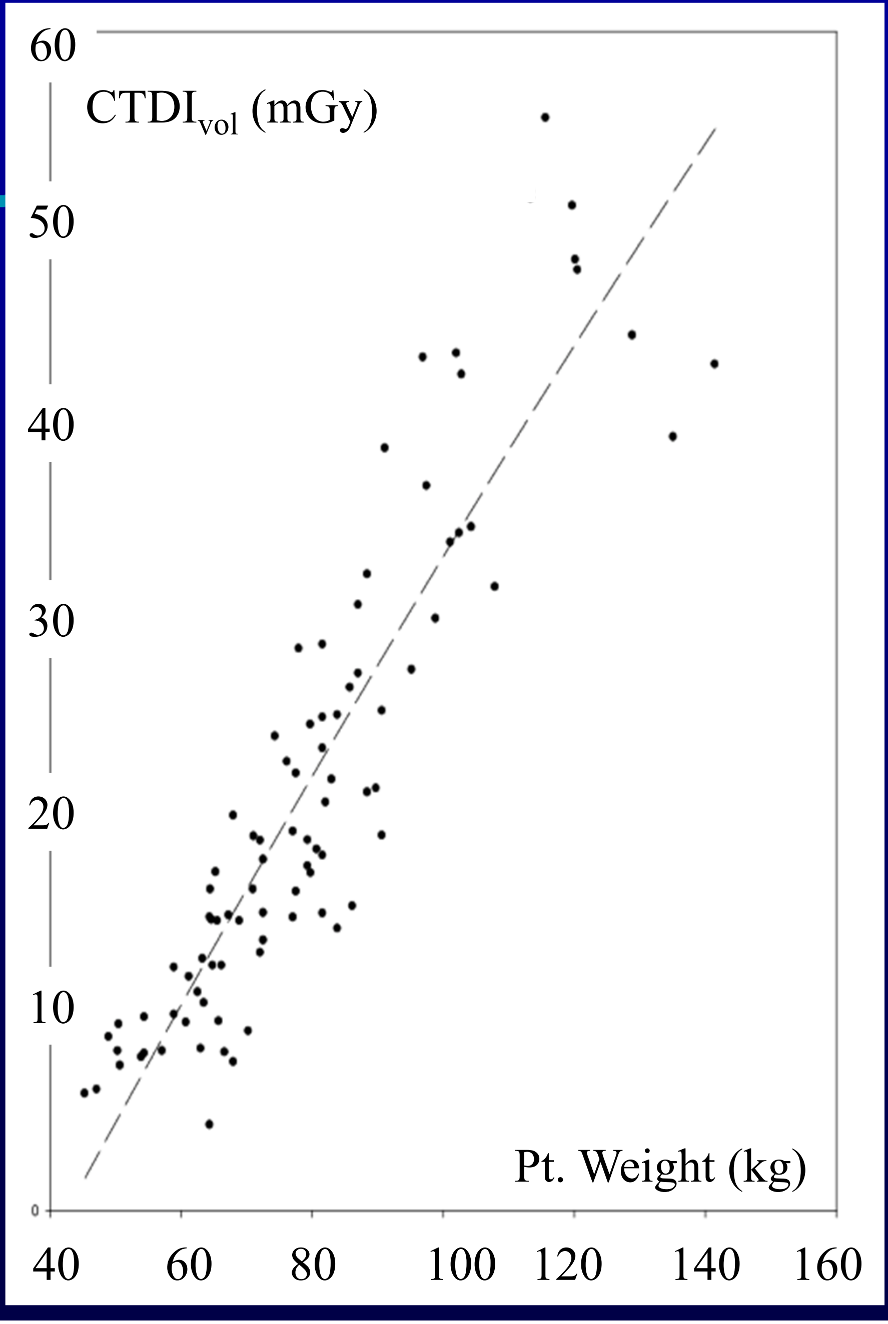
Dose vs. Weight

	60kg	100kg	
$CTDI_{vol}$	11	33	(3x)
Liver (mGy)	16	34	(2x)

Effective Dose:

Min – Max = 6 – 50 mSv

Israel, Cicchiello, Brink, Huda.
AJR 2010; 195:1342–1346

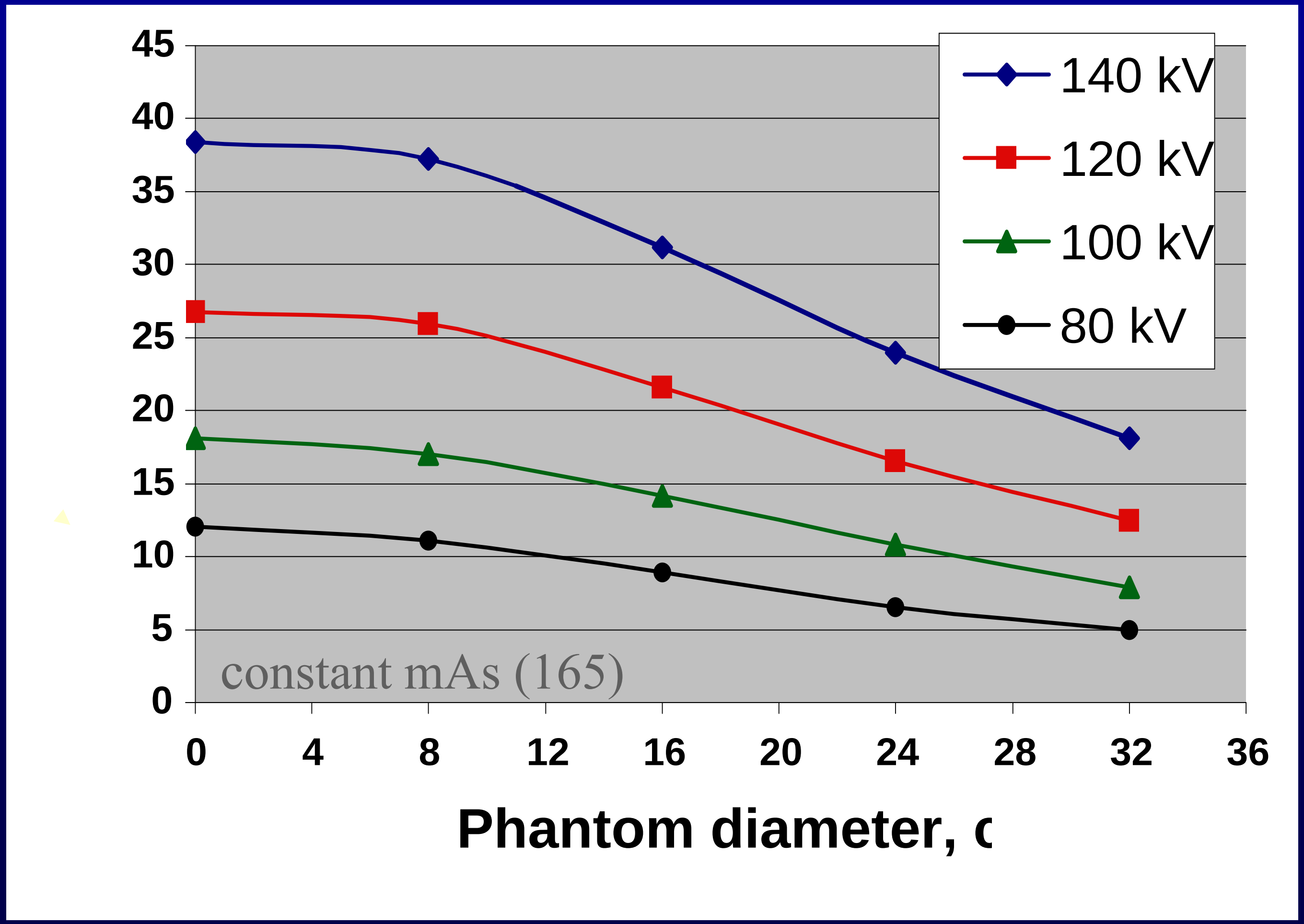


Low kVp -- Rationale

• K-edge of Iodine	32 keV
• Mean photon energy	
– 80 kVp	44 keV
– 100 kVp	52 keV
– 120 kVp	57 keV
– 140 kVp	62 keV

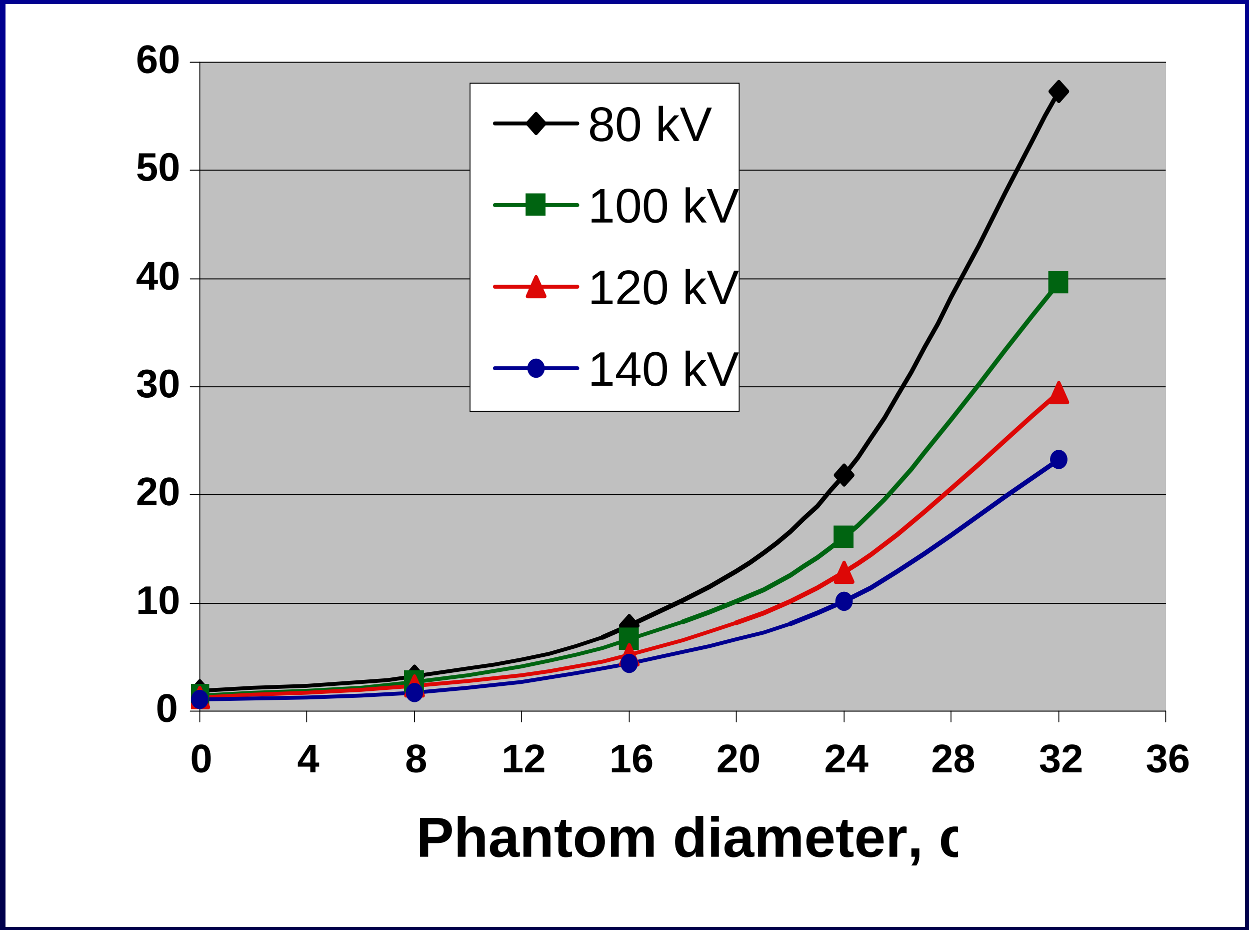
Huda W, et al. Radiology 2000; 217:430

Effect of kV on Dose



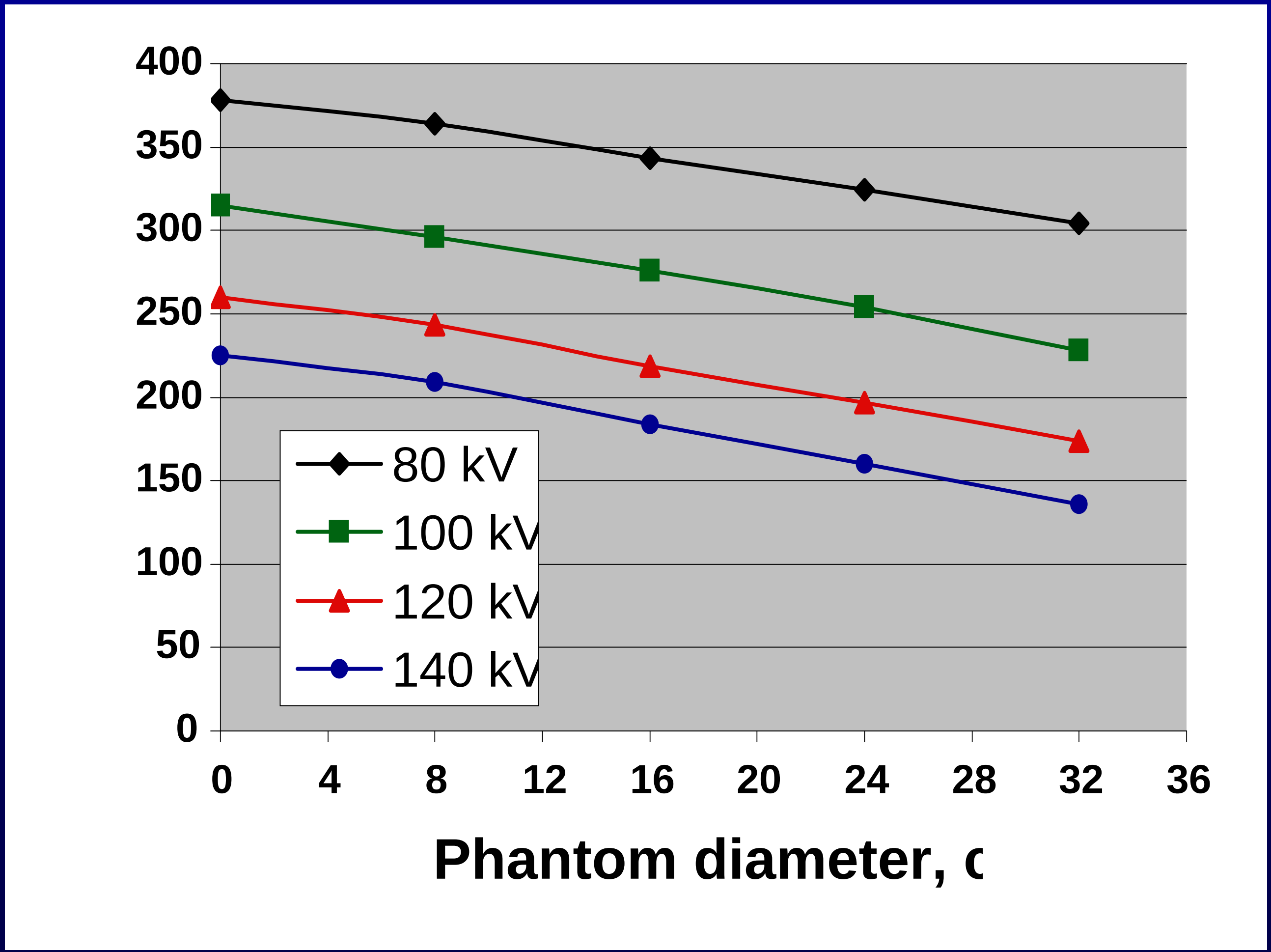
Courtesy of Marilyn Siegel, MD

Effective of kV on Image Noise



Courtesy of Marilyn Siegel, MD

Effect of kV on Iodine Contrast



Courtesy of Marilyn Siegel, MD

Low kV

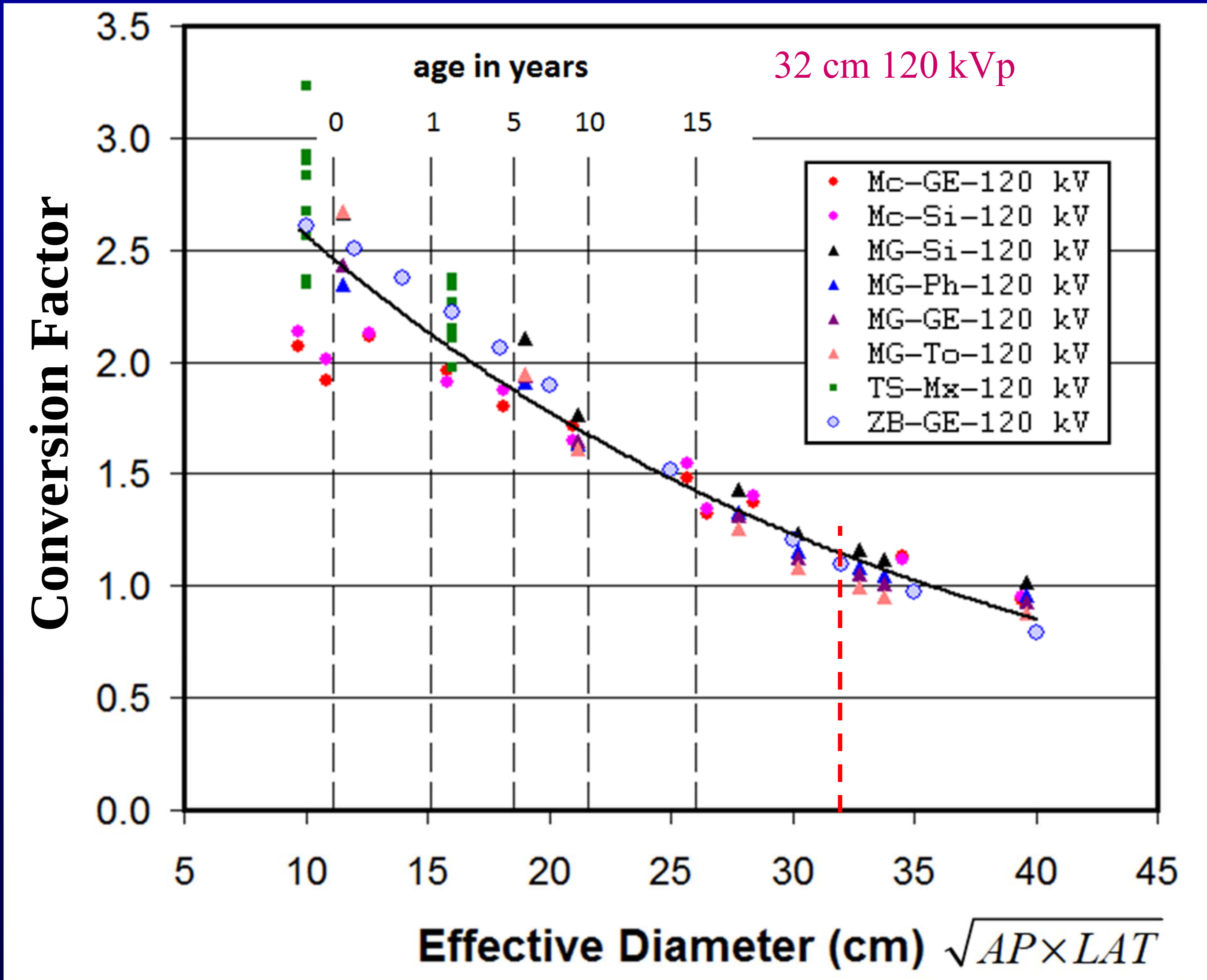
- Coronary CTA: 100 patients (≤ 85 kg)
  - Siemens Dual Source 64DCT
  - Retrospective gating
  - 120 kVp / 330 mAs: 12.7 mSv
  - 100 kVp / 330 mAs: 7.8 mSv
  - No significant impact on image quality

(12.7 mSv → 7.8 mSv: 40%)

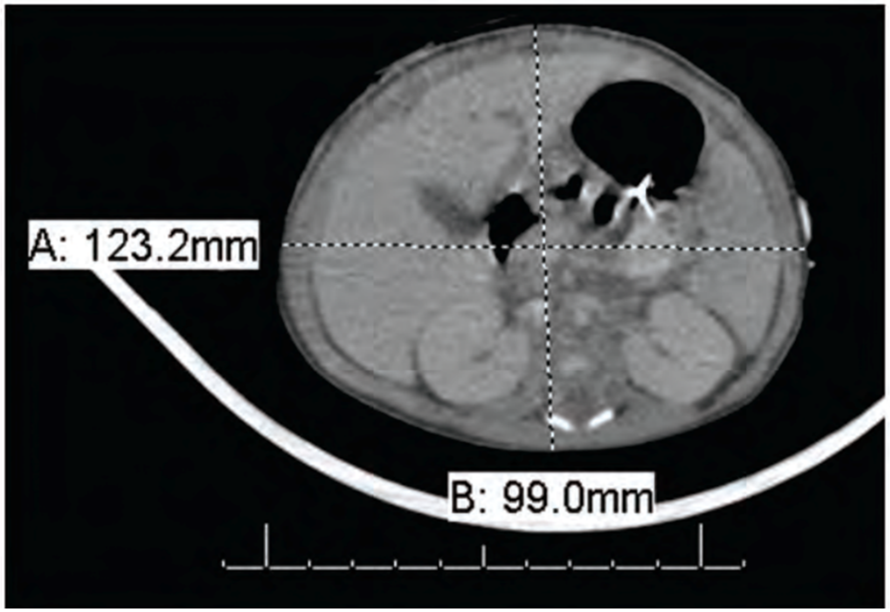
Pflederer T, et al. AJR 2009; 192:1045-1050

AAPM Working Group Report (#204)

Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations


32 cm 120 kVp
age in years
0
1
5
10
15
Mc-GE-120 kV
Mc-Si-120 kV
MG-Si-120 kV
MG-Ph-120 kV
MG-GE-120 kV
MG-To-120 kV
TS-Mx-120 kV
ZB-GE-120 kV
Conversion Factor
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
15
20
25
30
35
40
45
Effective Diameter (cm) $\sqrt{AP \times LAT}$

Example: Abdominal CT in a Child



CTDIvol = 5.40 mGy (32 cm phantom)
AP = 9.9cm Lat = 12.3cm
Sum = 22cm

Lat + AP Dim (cm)	Effective Dia (cm)	Conversion Factor
16	7.7	2.79
18	8.7	2.69
20	9.7	2.59
22	10.7	2.50

SSDE = 5.4 mGy x 2.50
= 13.0 mGy

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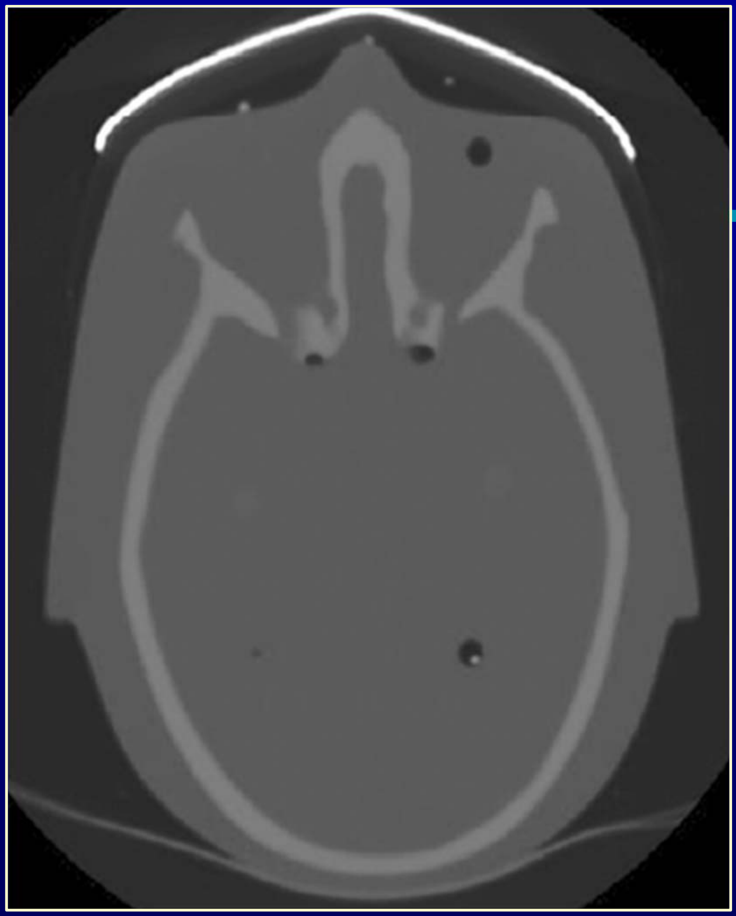
Orbit / Lens Dose

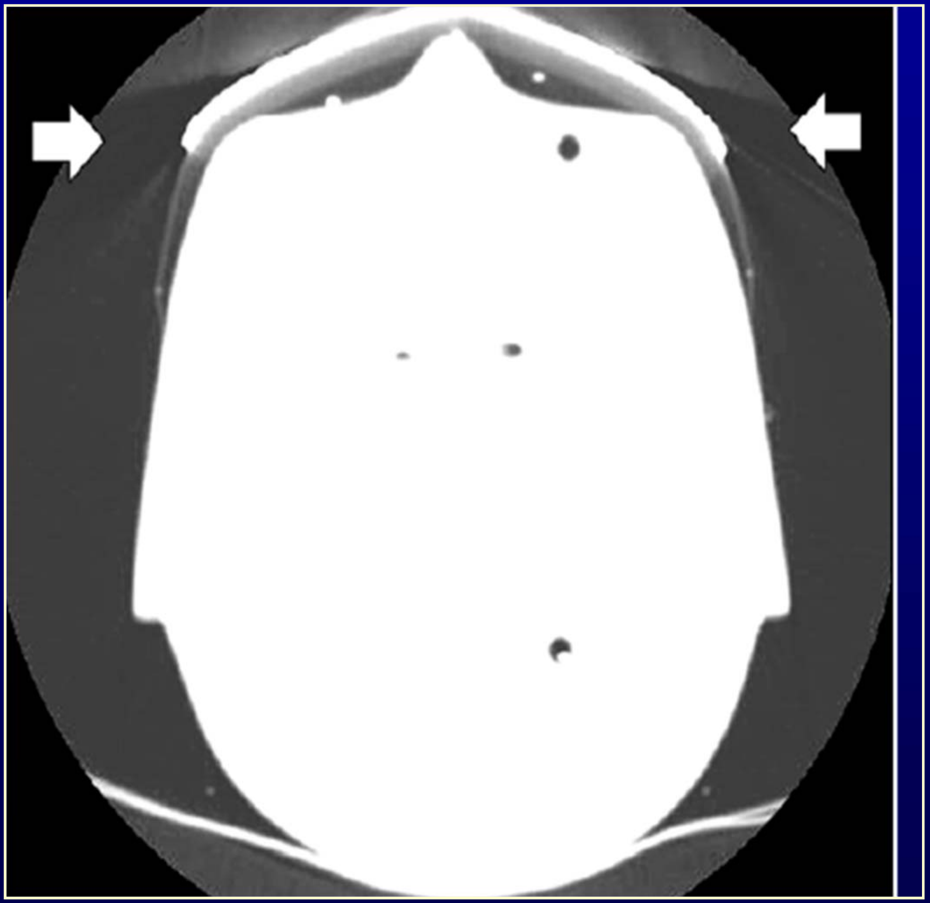
- Cataract Induction
  - 500-2000 mGy (adults); 250-1000 mGy (kids)
  - Annual limit for workers – 150 mGy (ICRP 60)
- Historically, head CT imparts:
  - Orbit dose: 50 mGy
  - Lens dose: 25 mGy
    - CT of sinuses, orbits, pituitary: 70 – 215 mGy

Mukundan S, et al. AJR 2007; 188:1648-1650
Maclennan AC. Clin Radiol 1995; 50:265-267

Eye Shields



Step-off pad moves artifacts ventrally



Mukundan S, et al. AJR 2007; 188:1648-1650

Orbit Dose

- Dose Reduction with Eye Shields
  - Orbit: 35 – 45%
  - Lens: 20 – 35%
- Supraorbital meatal baseline
  - Best approach to limit orbit / lens dose
  - Bismuth shields may be useful for helical scans
  - May not be possible with craniofacial, orbital, sinus, or temporal bone problems

Mukundan S, et al. AJR 2007; 188:1648-1650
Perisinakis K, et al. Med Phys 2005; 32:1024-30

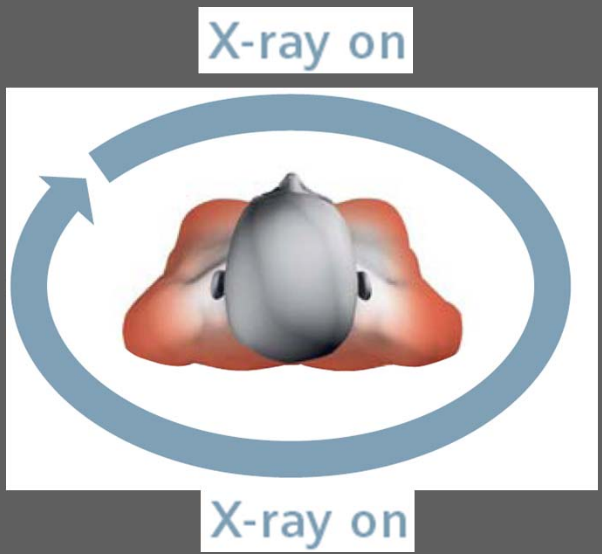
Orbit Dose

- Axial, IOM — 75 mGy
- Axial, SOB — 16 mGy
- Helical, SOB — 54 mGy
- Helical, SOB + Shield — 35 mGy

Clarkson LM, Arnold PM. Diagnostic Imaging Europe. June 26, 2009

Partial Scan – Dose Reduction

Conventional Technology



- **Full scan (360 degree radiation)**

Somatom Definition Flash, Siemens Medical Systems

Neck Irradiation

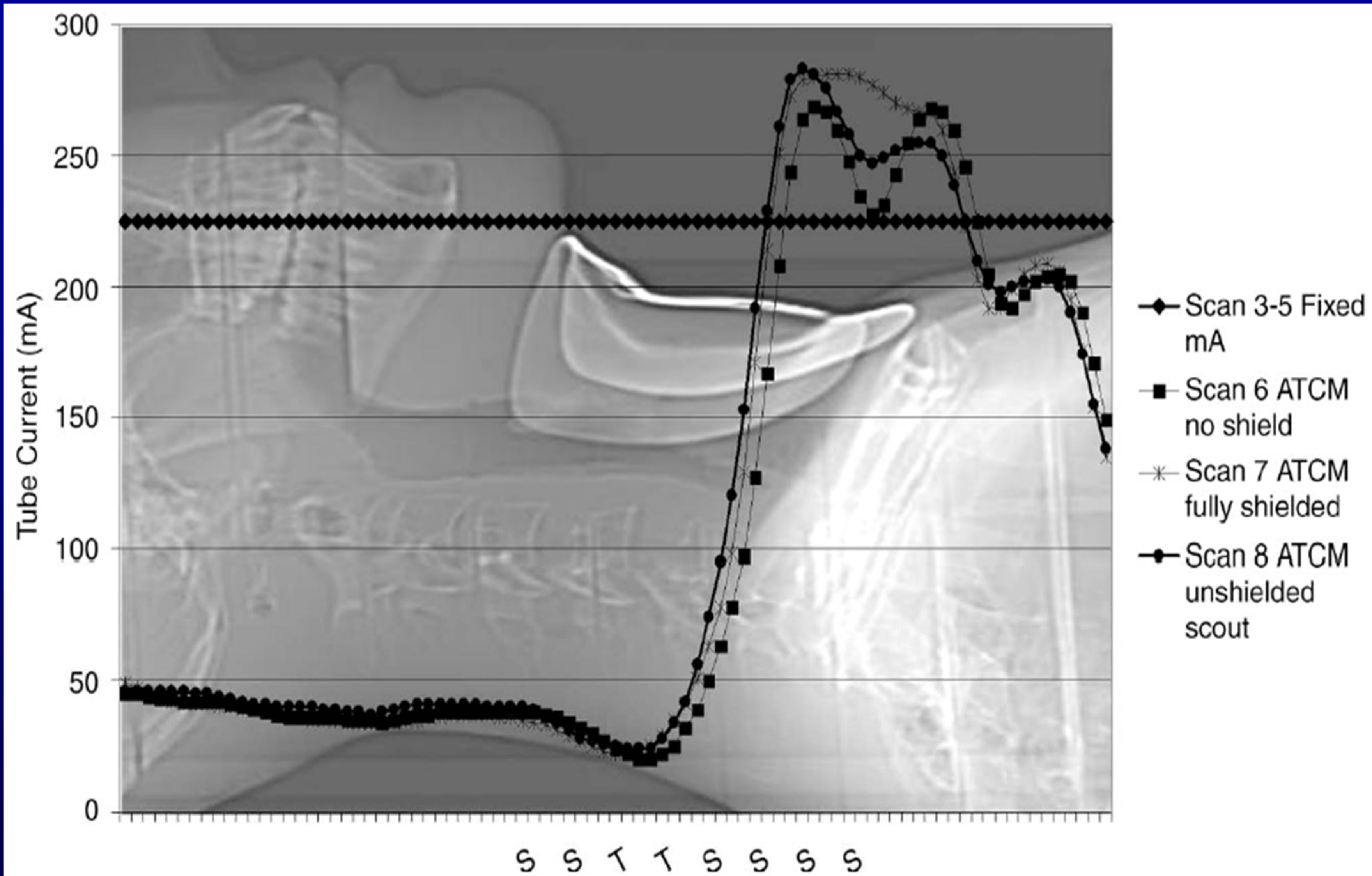
- Radiation is best defined factor in thyroid cancer, exposed in a variety of ways:
  - Therapy for ring-worm, hemangiomata
  - Nuclear accidents
  - Fall-out from nuclear bomb tests
  - Diagnostic imaging (CT of the head & neck)
    - Parallel rise of CT use and thyroid cancer -- ? link

Dawson P, Punwani S. European Journal of Radiology 2009; 69:74-79

Neck Irradiation

- Thyroid Dose
  - Head CT (scattered) 1 – 9 mGy
  - Neck CT (primary) 15 – 52 mGy
- Risk of thyroid cancer
  - Head CT 4 – 65 / million
  - Neck CT ~ 390 / million

Mazonakis M, et al. European Journal of Radiology 2007; 17:1352-7



Leswick DA, et al. Radiology 2008; 249: 752-580

Thyroid Shields, ATCM

- Thyroid Dose

– Fixed Tube Current	77 mGy	4 HU
– Bismuth Shield	45 mGy	74 HU
– ATCM (z-axis)	17 mGy	7 HU
– ATCM + Shield	12 mGy	113 HU

- ATCM (z-axis) is more effective than thyroid shields for reducing thyroid dose

Leswick DA, et al. Radiology 2008; 249: 572-580

High Resolution Neck Imaging

Parathyroid 4DCT: Evaluation of Radiation Dose Exposure during Preoperative Localization of Parathyroid Tumors in Primary Hyperparathyroidism

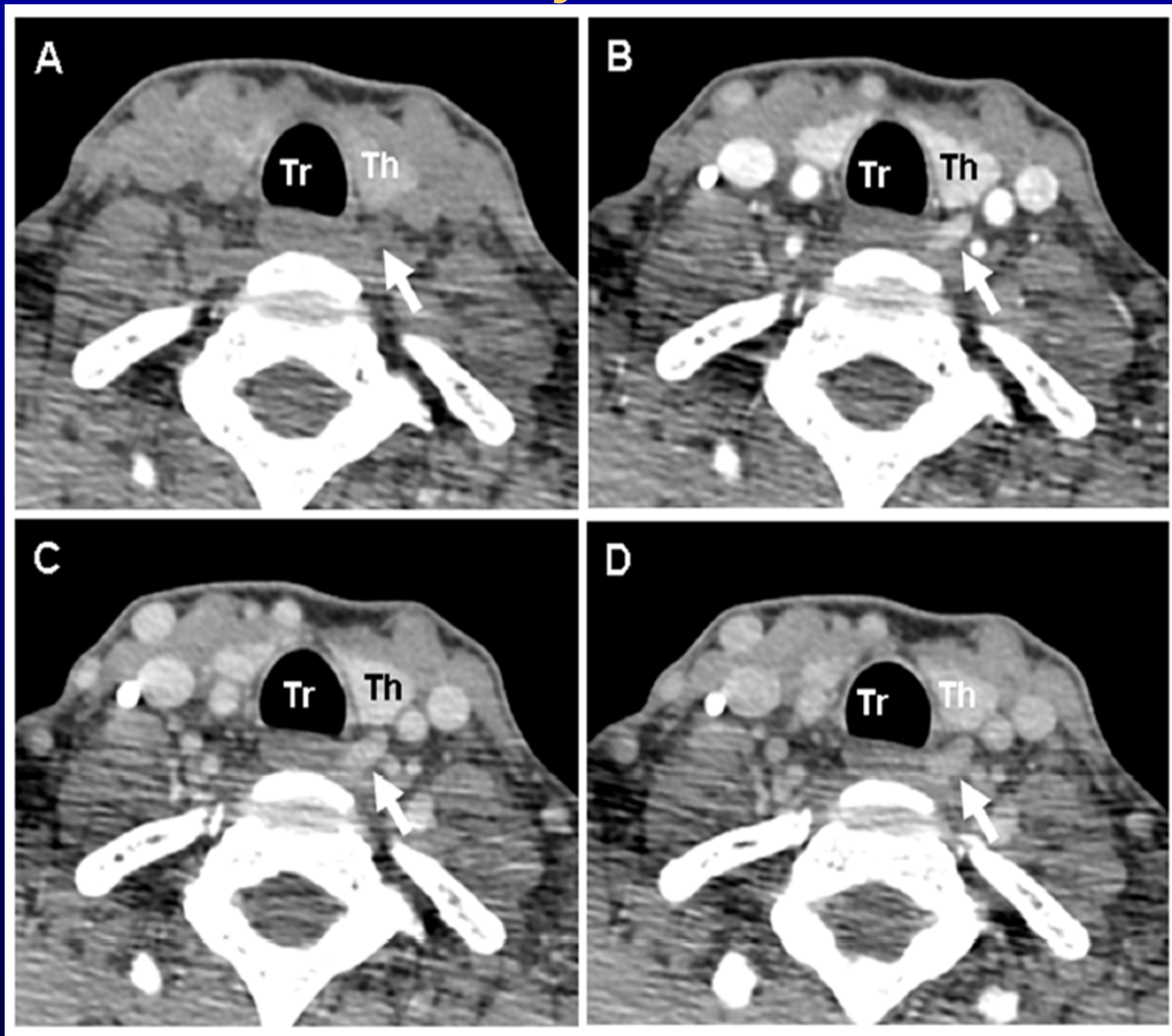
Amit Mahajan MD[1], Lee F. Starker MD[2], Monica Ghita PhD[1], Robert Udelsman MD[1],

James A. Brink, MD[1], and Tobias Carling MD PhD[2]

Yale University School of Medicine, Departments of Diagnostic Radiology[1] and

Surgery[2], New Haven, CT

4DCT – Parathyroid Adenoma



4DCT vs. Sestamibi Scan

- 4DCT: 1.25mm helical scan at 0, 30, 60, 90 sec
  - 120 kV, 128 mAs, CTDIvol=10.8 mGy, DLP=248 mGy cm
- SeS: 20 mCi of Tc-99m sestamibi
- Dose Estimation:
  - 4DCT: ImPACT Dose Calculator
  - SeS: NUREG Method (US Nuclear Regulatory Commission)
- Cancer Risk Estimation:
  - Age and gender-dependent risk factors from BEIR VII

Parathyroid Imaging

- Effective Dose:
  - 4DCT: 10.4 mSv
  - SeS: 7.8 mSv

Organ Doses

ORGAN	Absorbed Dose (mGy)	
	SeS	4DCT
Adrenals	3.2	0.8
Brain	1.3	5.6
Breasts	1.3	2.6
Colon	33.0	0.0
Esophagus	1.7	27.2
Gallbladder Wall	13.4	0.3
Small Intestine	20.1	0.0
Stomach	3.9	0.5
Heart Wall	3.3	4.4
Kidneys	13.4	0.2
Liver	3.8	0.8
Lungs	1.8	17.2

ORGAN	Absorbed Dose (mGy)	
	SeS	4DCT
Muscle	2.8	10.0
Ovaries	10.4	0.0
Pancreas	3.7	0.7
Red Marrow	3.3	10.8
Bone Surfaces	4.3	24.8
Skin	1.4	9.6
Spleen	3.9	0.7
Thymus	1.7	27.2
Thyroid	1.6	92.0
Urinary Bladder Wall	27.5	0.0
Uterus	8.9	0.0

Combined Cancer Risk From 4DCT, SeS

Age at Exposure (years)	Colon Cancers per 100,000 Persons Exposed		Thyroid Cancers per 100,000 Persons Exposed	
	Males	Females	Males	Females
0	111	73	106	583
5	94	62	70	385
10	80	52	46	253
15	67	44	30	164
20	57	38	19	104
30	41	27	8	38
40	40	26	3	13
50	37	24	1	4
60	31	20	0	1
70	21	15	0	0
80	10	8	0	0

Outline

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The National Lung Screening Trial: Overview and Study Design[1]

National Lung Screening Trial Research Team

- > 53,000 current or former heavy smokers
  - Includes ex-smokers who quit within 15 yrs
  - Age 55 – 74 years
  - ≥ 30 pack years
  - 33 US institutions
  - Recruitment targeted to mirror demographics of US Census Tobacco Use Supplement (TUS) from 2002-2004

Radiology: Volume 258: Number 1—January 2011

NLST Preliminary Results

- Patients were randomized to low-dose CT or CXR at beginning, and then received 2 more studies over next 2 yrs:
  - Low Dose CT 354 ung Ca deaths
  - CXR 442 Lung Ca deaths
  - 20% reduction in Lung Ca deaths (90% power)
  - 7% reduction in All-Cause deaths

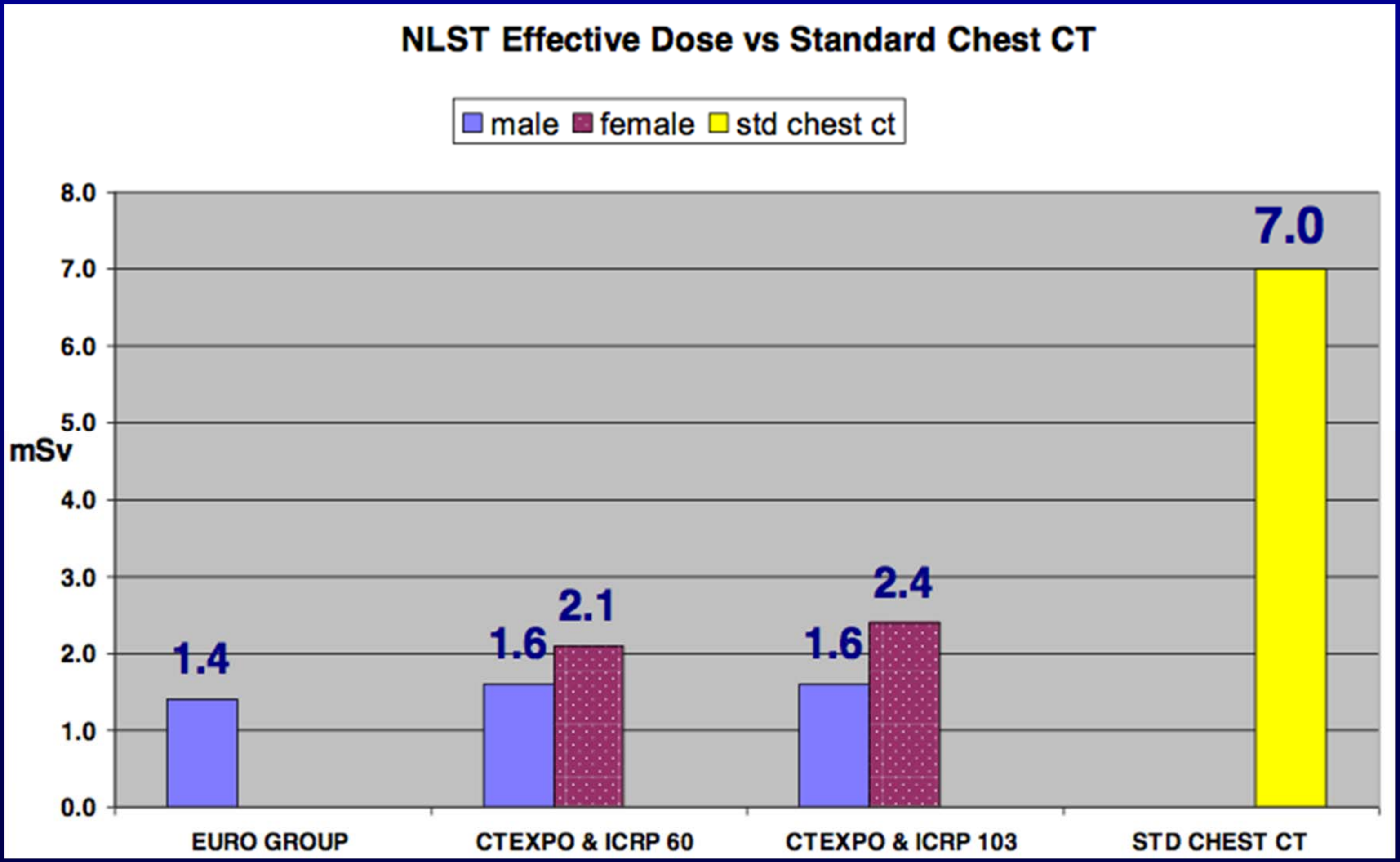
Radiology: Volume 258: Number 1—January 2011

NLST Low-Dose CT Technique

Helical acquisition	
Positioning	Supine; arms elevated above the head
Inspiration	Suspended maximal
Voltage (kVp)	120–140
Tube current–time product (mAs)	40–80 (dependent on participant body habitus)
Detector collimation (mm)	≤2.5
Nominal reconstructed section width (mm)	1.0–3.2
Reconstruction interval (mm)	1.0–2.5
Reconstruction algorithm	Soft tissue or thin section
Scanning time (sec)	<25

Radiology: Volume 258: Number 1—January 2011

NSLT: $CTDI_{vol}$ (mean) = 2.9 mGy



Accessed on 9/18/11 -- http://www.cancer.gov/newscenter/qa/2002/RSNA2010Larke

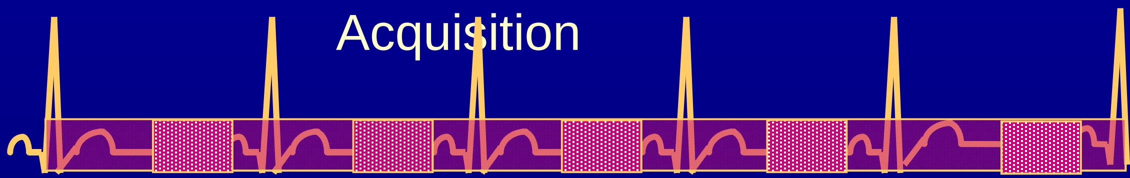
Cardiac CT

	Dose (mSv)	*Relative Dose*
Chest x-ray	0.02	1
Coronary Calcium:		
EBT/MDCT	0.8/1-4	40/50-200
Annual Background Rad.	3.6	180
Coronary angiogram	3-10	150-500
Coronary CTA (Retrospective Gating)		
MDCT(16)	9-14	450-700
MDCT(64)	16	800
MDCT(64 ”Triple”)	35	1,750

Adapted from Morin et al., *Circ.* 2003;107:917-922 and McCullough *Herz* 2003;28:1-6

Prospective Cardiac Gating

Retrospective Gated Helical Acquisition

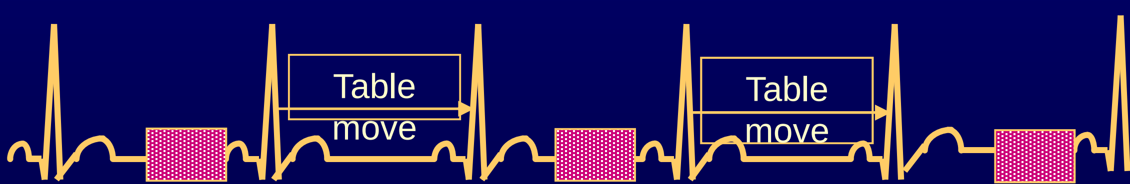


Multiphase Data

Functional analysis

6-15 mSv

Prospective Gated Axial Acquisition



X-ray on time

Target Phase range

Single phase or phase range

Low dose acquisition

3-6 mSv

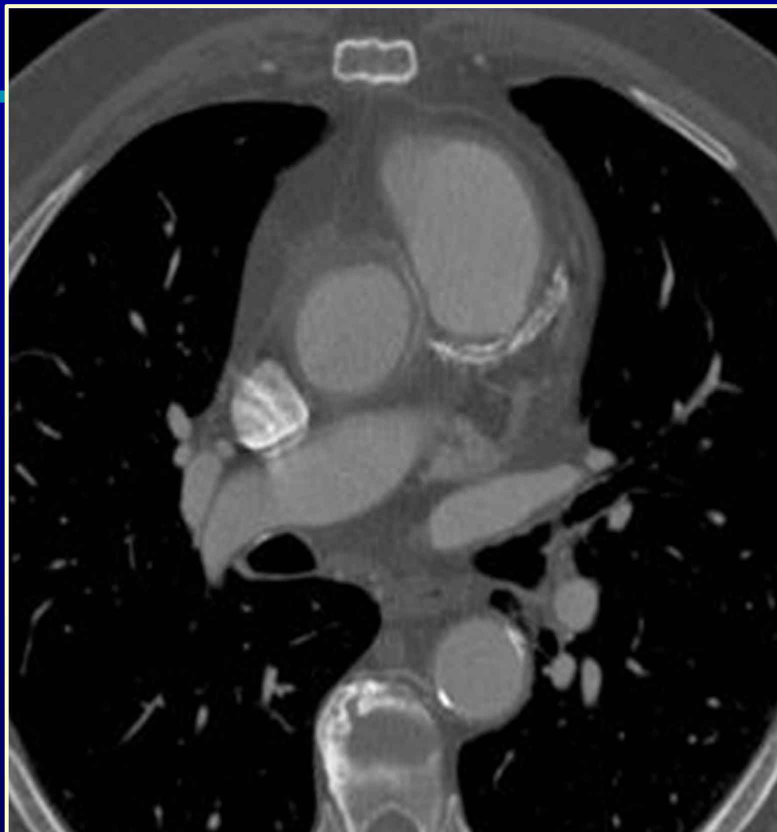
Diagnostic Cath: 3 - 5 mSv

Prospective ECG Gating

- 41 CCTA patients
  - GE 64DCT, prospective gating
  - Effective dose: 1.1-3.0 mSv (mean = 2.1)
  - Non-diagnostic image quality in 5%
    - Step artifacts from lack of overlap
    - May require some overlap, dose increase

Husmann L, et al. (Univ. Hospital Zurich), Eur Heart J.12/07

Coronary CTA; 100 kVp; ASIR

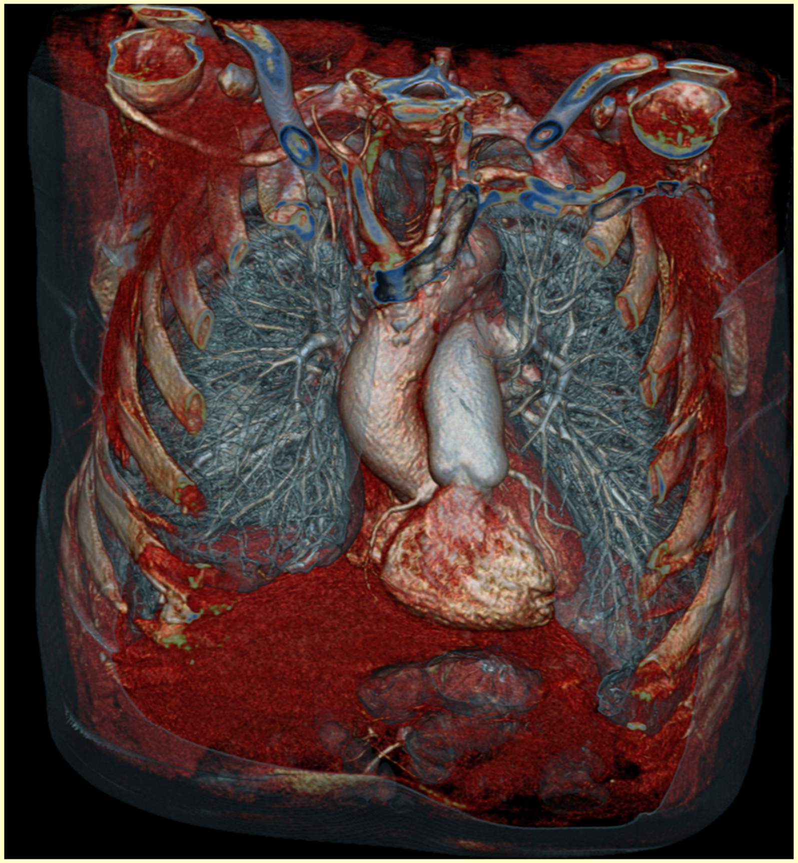


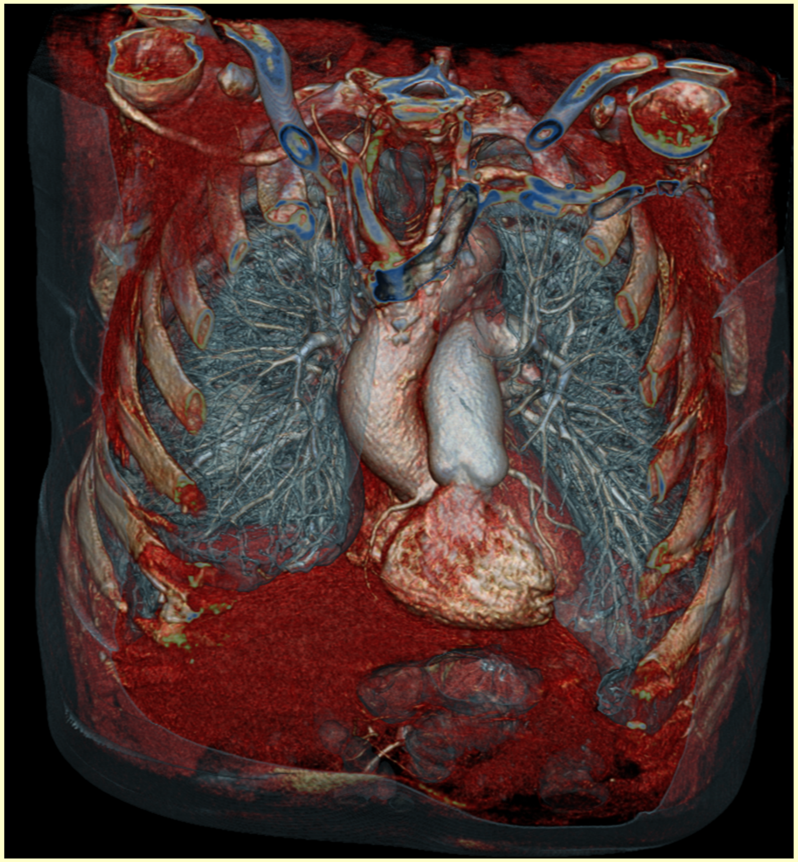
2008 – Retrospective Gating; No ASIR
CTDIvol = 21.6 mGy
Eff. Dose = 28 mSv

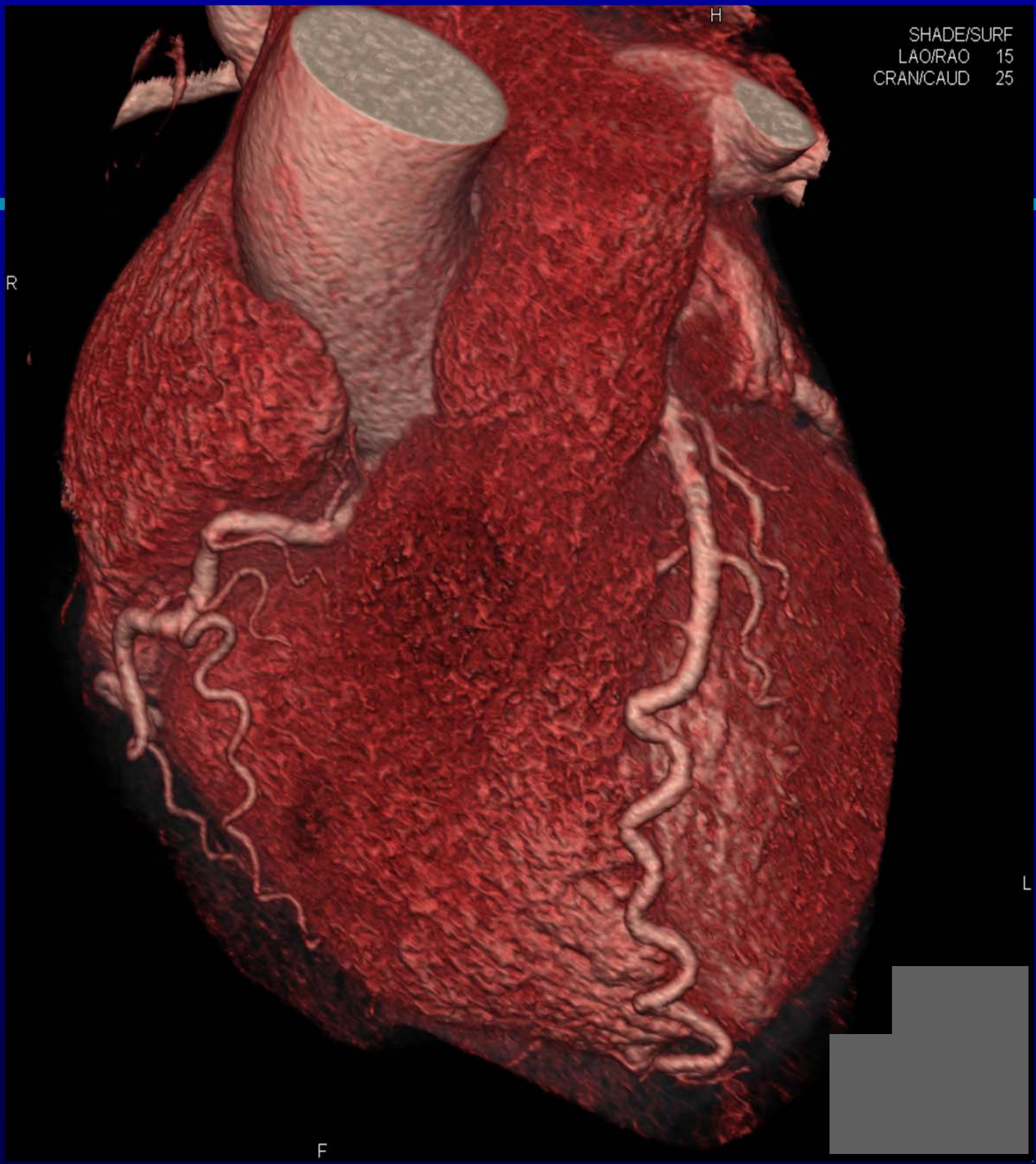
2009 – Prospective Gating; 60% ASIR
CTDIvol = 6.8 mGy
Eff. Dose = 4.5 mSv

Siemens Dual Source Flash

SSCT Spiral







Dual Source Cardiac

Temp Res. 75 ms

Spat Res. 0.33 mm

0.35 s for 149 mm

Rotation 0.28 s

100 kV; 290 mAs

0.9 mSv

Courtesy of Friedrich-Alexander University Erlangen-Nuremberg - Institute of Medical Physics / Erlangen, Germany

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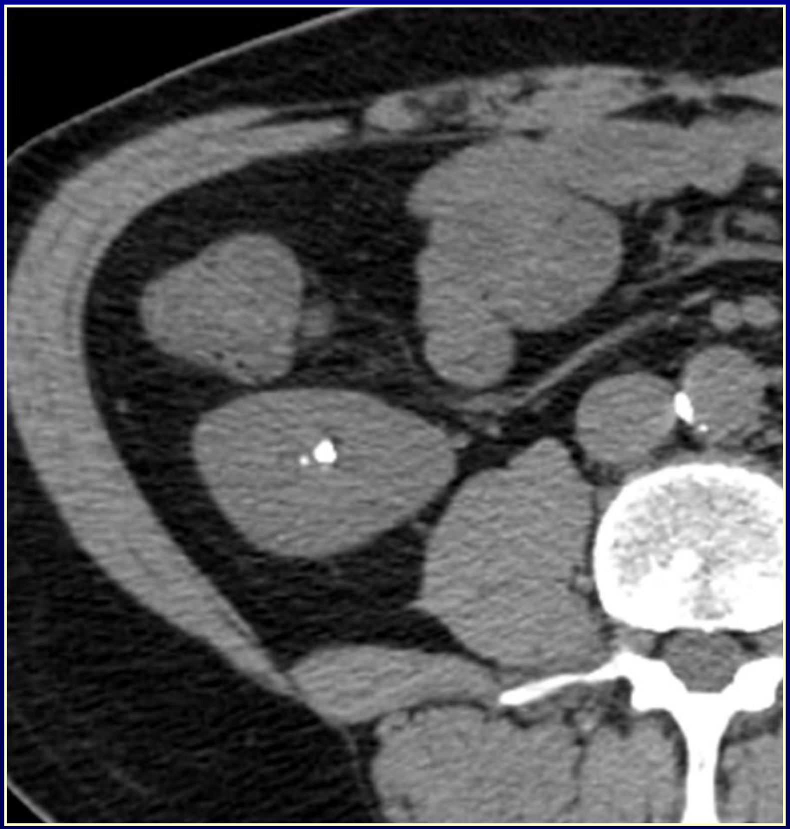
16 Slice

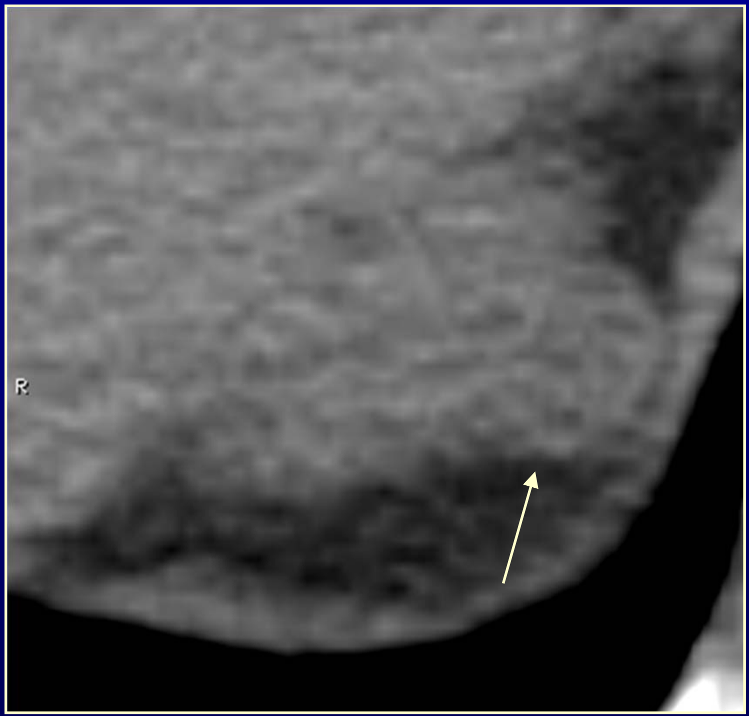
16x1.25, 2.5/2.5, 120kV
530msec, 439 mA, pitch = 1.375
effective mAs = 169.2 eff mAs

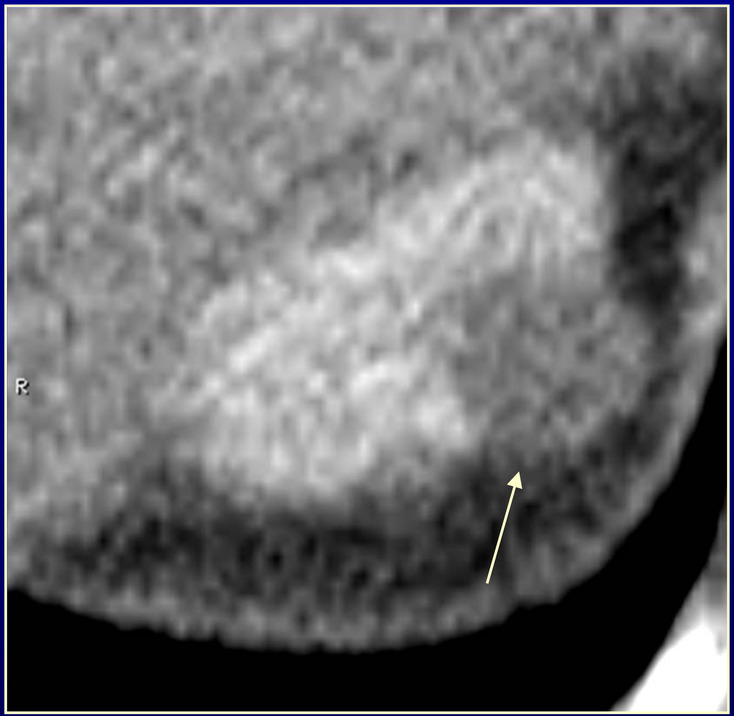
64 Slice



64x0.625, 2.5/2.5, 120kV
500msec, 637 mA, pitch = 0.984
effective mAs = 323.7 eff mAs

Renal Cyst (?)





- Pre -- 440 mA, 1133 ms 3.75mm helical 4HU
- Post--440 mA, 668 ms 3.75mm helical 18HU

Renal Cell Carcinoma

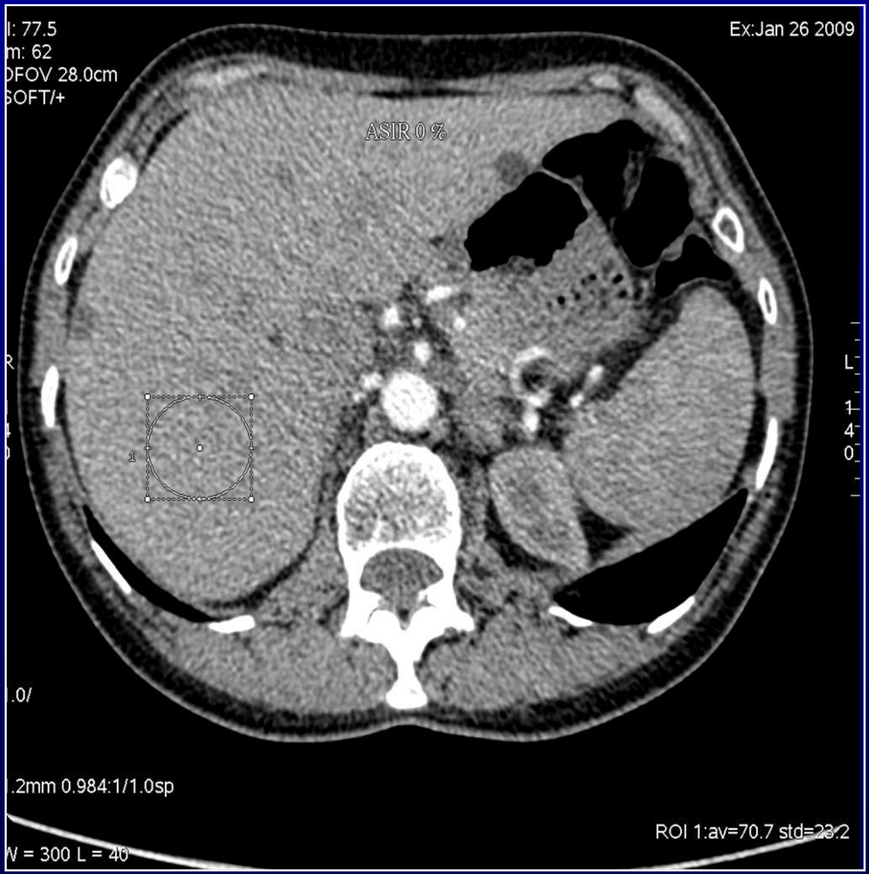
- Pre -- 200mA, 2000ms 3.75mm axial 8HU
- Post -- 200mA, 2000ms 3.75mm axial 22HU

Adaptive Statistical Iterative Recon. (ASIR)

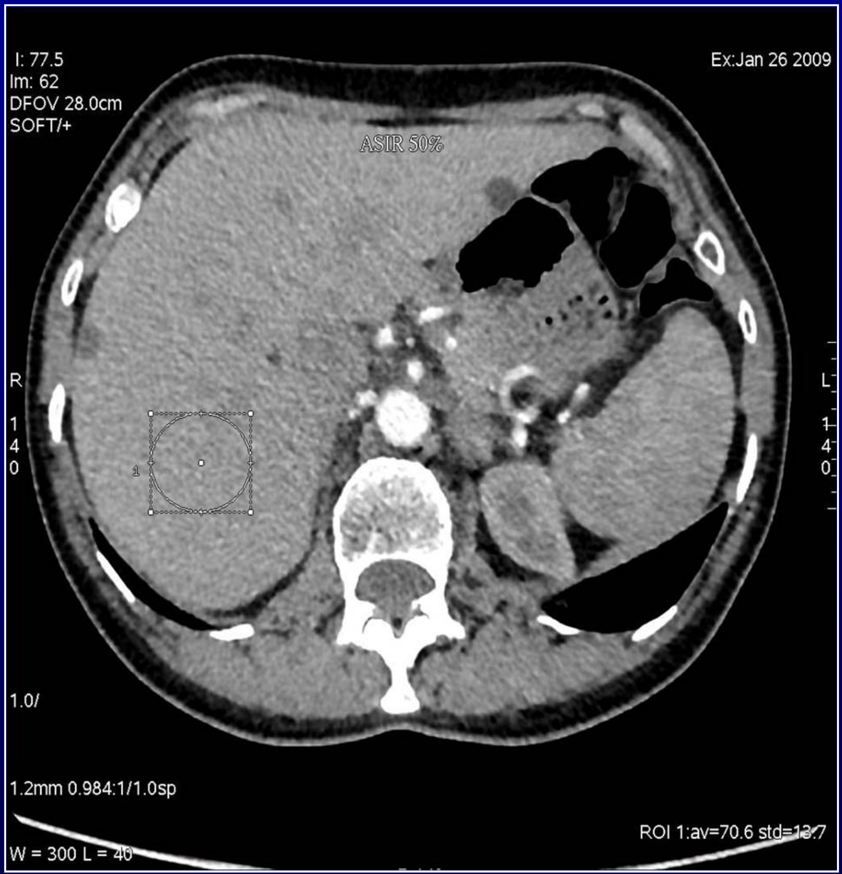
Dose reduction of 35% to 65%

GE Healthcare, Inc.

ASIR: DLP=136 mGy-cm (2.0 mSv)



Noise: 23.2



ASIR 50 % – Noise: 13.7

GE Healthcare, Inc.

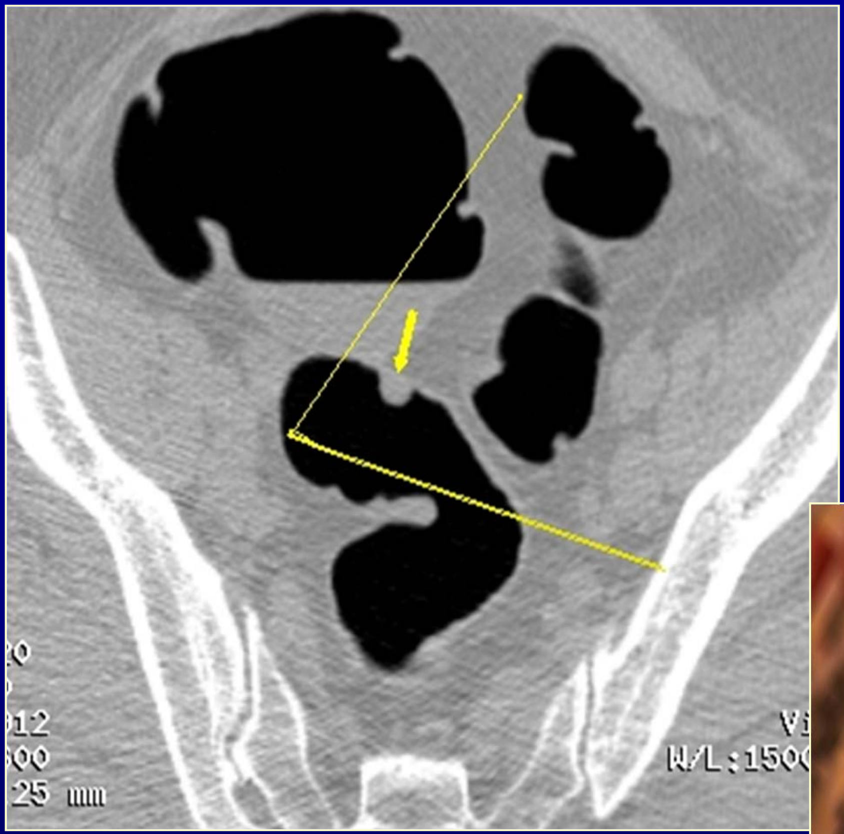
CT Colonography

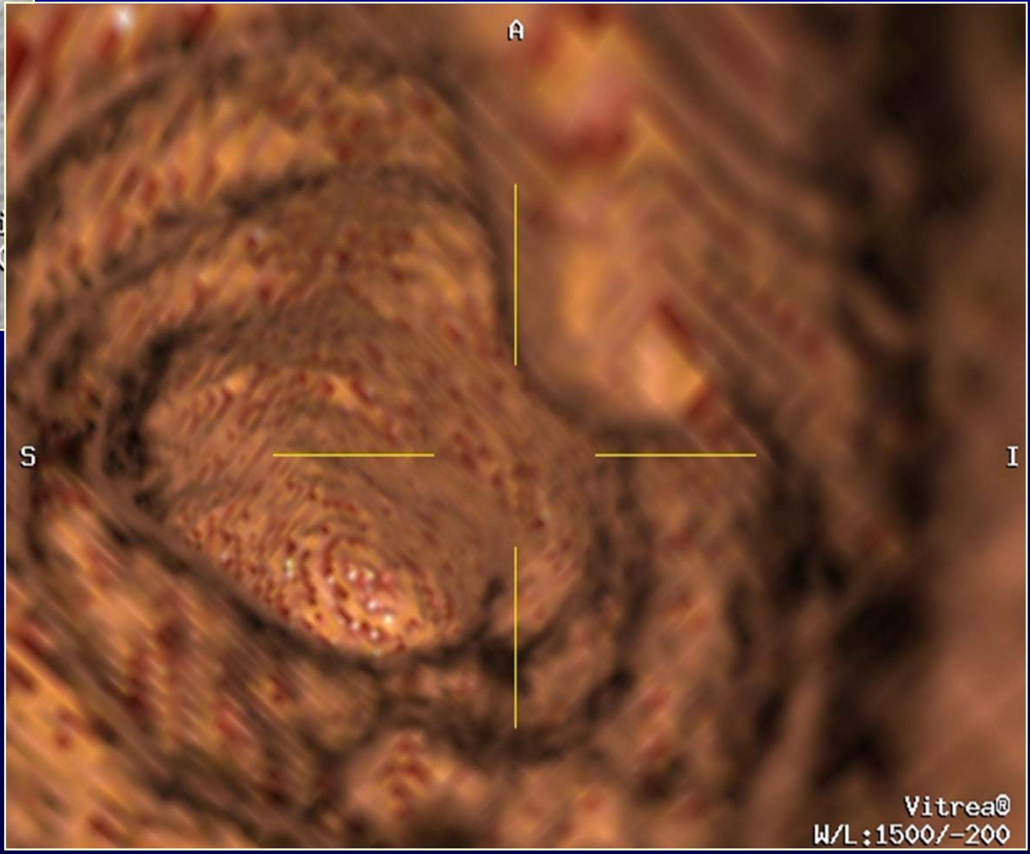
NYU: Siemens 4DCT

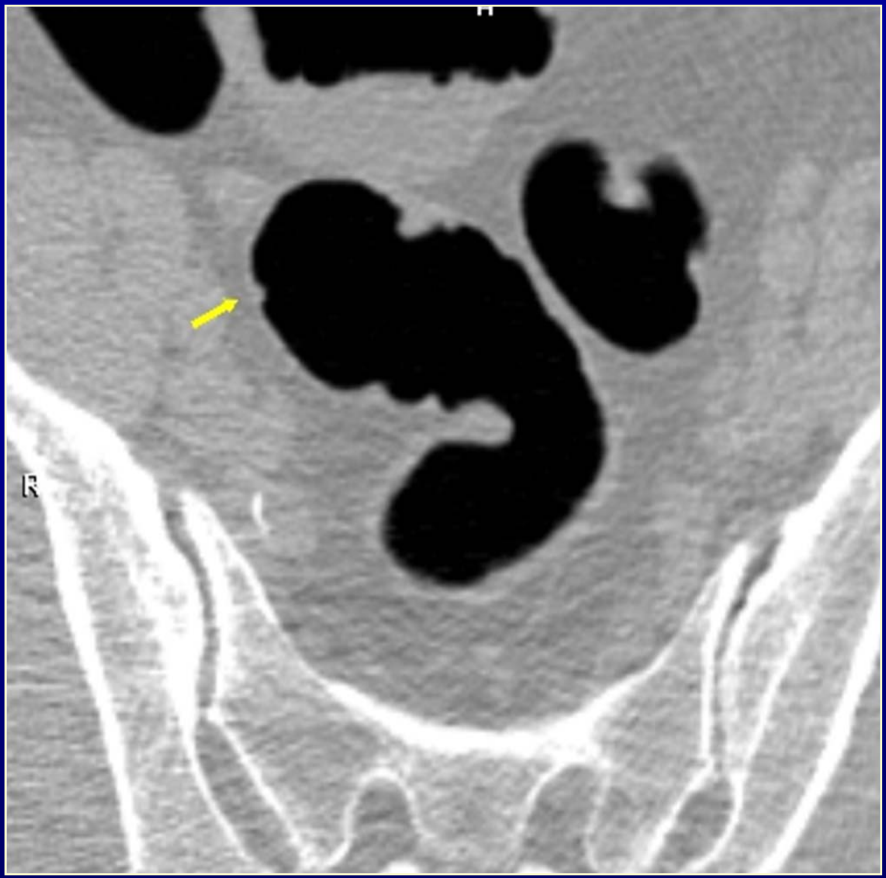
- 50 “effective” mAs
- Effective dose = 5 to 7 mSv
- Barium enema = 6 to 8 mSv

Macari et al. Radiology 2002; 224:383-392

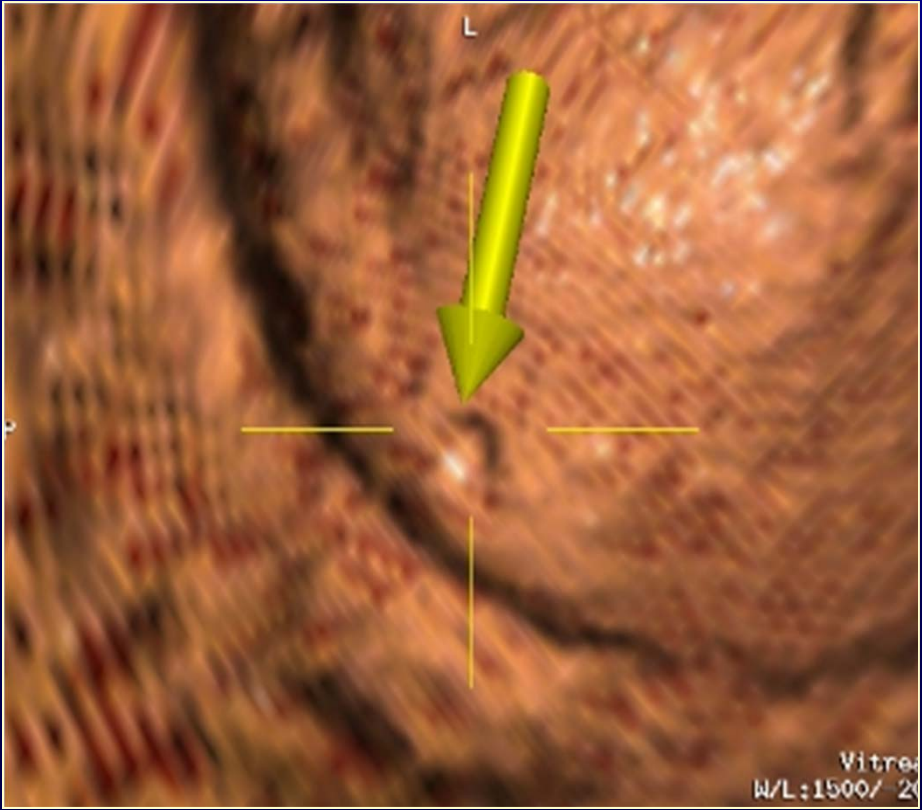
9 mm Polyp: Sigmoid Colon







3 mm Polyp: Sigmoid Colon

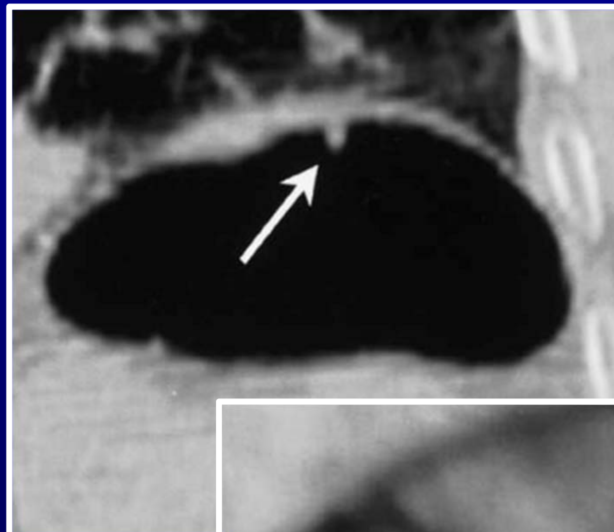


Feasibility of ultra-low-dose multislice CT colonography for the detection of colorectal lesions: preliminary experience

Riccardo Iannaccone
Andrea Laghi
Carlo Catalano
Filippo Mangiapane
Francesca Piacentini
Roberto Passariello

4DCT, 2.5mm
140 kVp, 10 mAs
(supine and prone)

Effective Dose:
1.7 mSv (for men)
2.3 mSv (for women)



Eur Radiol (2003) 13:1297–1302

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Decision Support

Radiology

Effect of Computerized Order Entry with Integrated Decision Support on the Growth of Outpatient Procedure Volumes: Seven-year Time Series Analysis[1]

Christopher L. Sistrom, MD, MPH
Pragya A. Dang, MD
Jeffrey B. Weilburg, MD
Keith J. Dreyer, DO, PhD
Daniel I. Rosenthal, MD
James H. Thrall, MD

Purpose: To determine the effect of a computerized radiology order entry (ROE) and decision support (DS) system on growth rate of outpatient computed tomography (CT), magnetic resonance (MR) imaging, and ultrasonography (US) procedure volumes over time at a large metropolitan academic medical center.

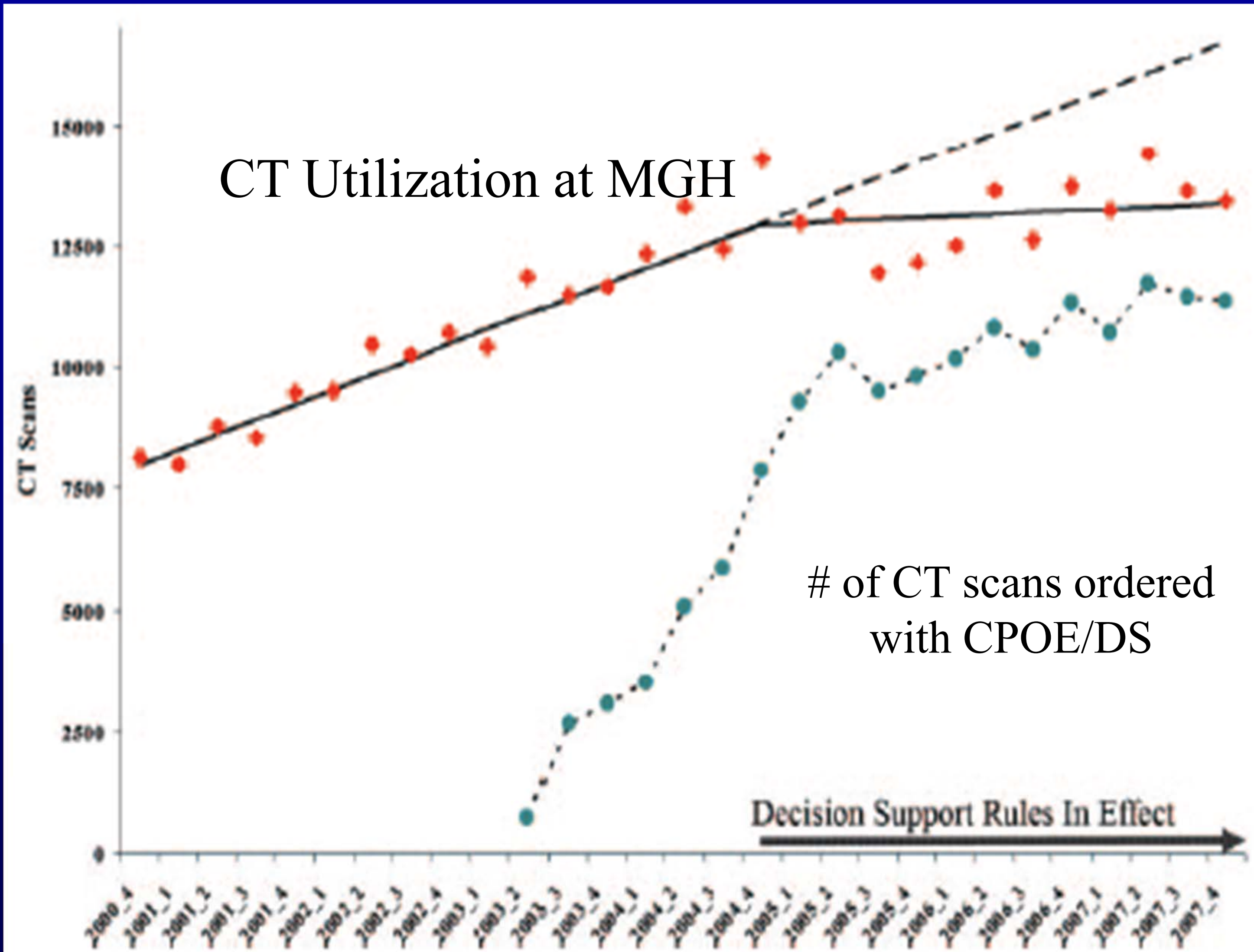
Radiology 2009; 251: 147-155

Decision Support

Results: There was a significant decrease in CT volume growth (274 per quarter) and growth rate (2.75% per quarter) after ROE and DS system implementation ($P < .001$). For MR imaging, growth rate decreased significantly (1.2%, $P = .016$) after ROE and DS system implementation; however, there was no significant change in quarterly volume growth. With US, quarterly volume growth ($n = 98$, $P = .014$) and growth rate (1.3%, $P = .001$) decreased significantly after ROE implementation. These changes occurred during a steady growth in clinic visit volumes in the associated referral practices.

Conclusion: Substantial decreases in the growth of outpatient CT and US procedure volume coincident with ROE implementation (supplemented by DS for CT) were observed. The utilization of outpatient MR imaging decreased less impressively, with only the rate of growth being significantly lower after interventions were in effect.

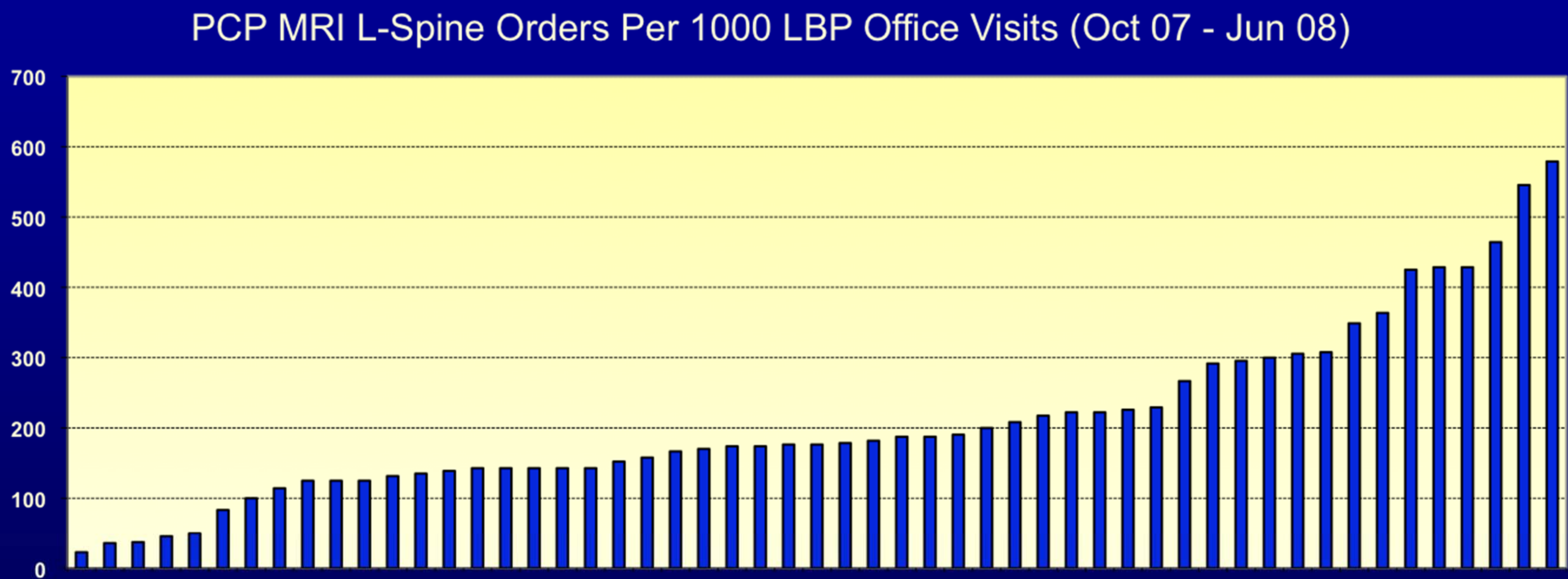
Radiology 2009; 251: 147-155



Radiology 2009; 251: 147-155

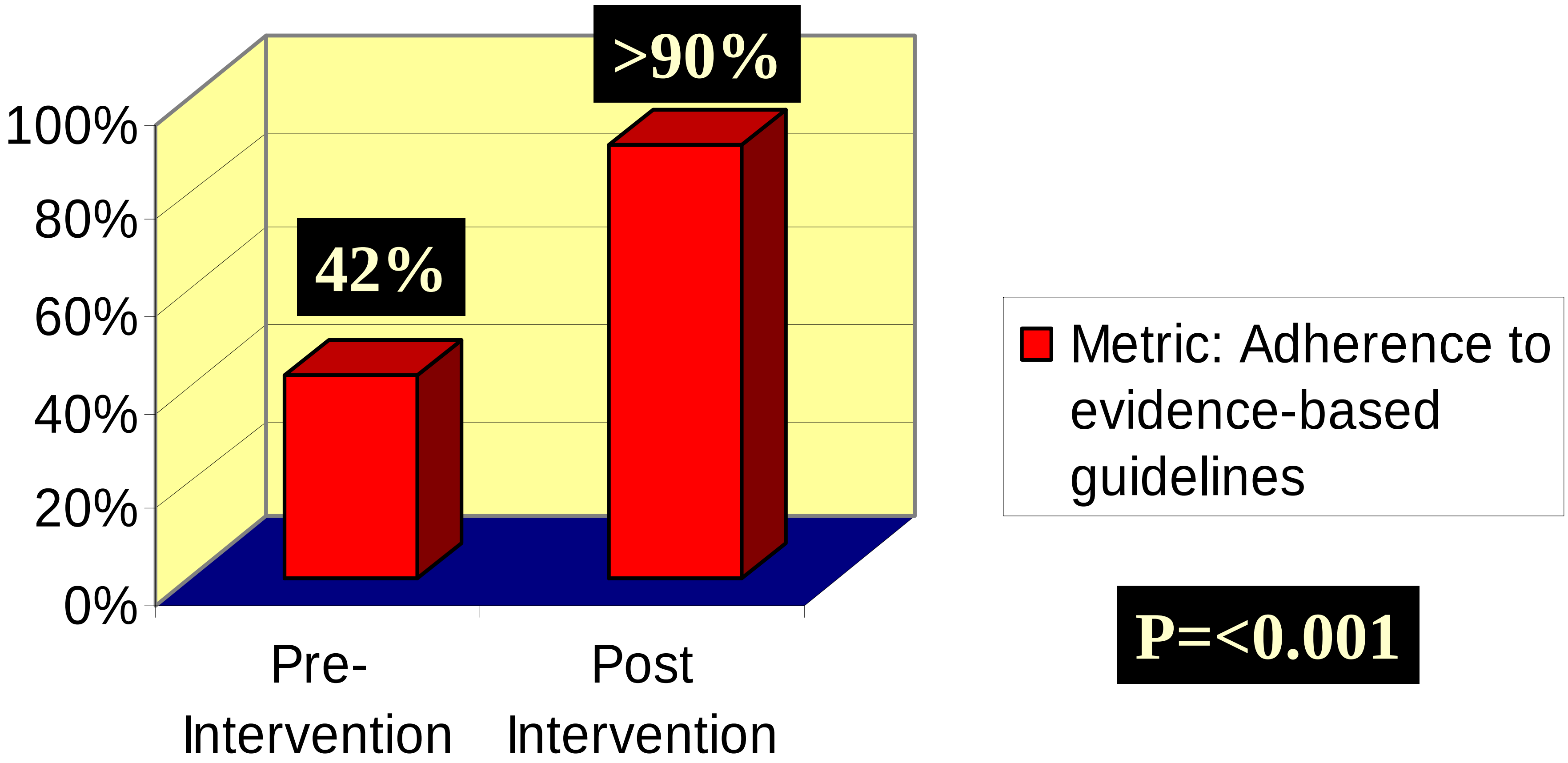
PCP Practice Pattern Variation

MRI L Spine for low back pain



Courtesy of
Ramin Khorasani, MD, MPH 2009

Appropriateness of L-Spine MRI for evaluation of low back pain by PCPs



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