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
- Methods to streamline protocol selection based on clinical indication
  - 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

91 pts for Chest, Abdomen, Pelvis CT w/ 64DCT
- NI=11.5, 5mm, rot=1s, pitch=1, 120kV, mA_{max}=800 mA

CTD_{vol} obtained from console + Impact Dose Calculator
- organ doses computed for a 70kg patient

Patient doses were calculated by correcting for pt. size
Dose vs. Weight

<table>
<thead>
<tr>
<th>Pt. Weight (kg)</th>
<th>CTDI$_{vol}$ (mGy)</th>
<th>Liver (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60kg</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>100kg</td>
<td>33 (3x)</td>
<td>34 (2x)</td>
</tr>
</tbody>
</table>

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

**Effect of kV on Dose**

![Graph showing the effect of kV on dose with different kV settings: 140 kV, 120 kV, 100 kV, and 80 kV. The graph illustrates how phantom diameter affects dose at constant mAs (165).](image)

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 ($\leq 85$ kg)
  - Siemens Dual Source 64DCT
  - Retrospective gating
  - $120 \text{kVp} / 330 \text{mAs}: 12.7 \text{mSv}$
  - $100 \text{kVp} / 330 \text{mAs}: 7.8 \text{mSv}$
  - No significant impact on image quality

$Pfleiderer\ T,\ et\ al.\ AJR\ 2009;\ 192:1045-1050$
Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations
**Example: Abdominal CT in a Child**

CTDI\textsubscript{vol} = 5.40 mGy (32 cm phantom)

$AP = 9.9\text{cm}$ \hspace{1cm} $Lat = 12.3\text{cm}$

$Sum = 22\text{cm}$

SSDE $= 5.4 \text{ mGy x 2.50}$

$= 13.0 \text{ mGy}$
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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*

*Maclennnan 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*

Orbit Dose

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

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, hemangiomas
  – Nuclear accidents
  – Fall-out from nuclear bomb tests
  – Diagnostic imaging (CT of the head & neck)
    • Parallel rise of CT use and thyroid cancer - ? link

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

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

High Resolution Neck Imaging

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

Amit Mahajan MD¹, Lee F. Starker MD², Monica Ghita PhD¹, Robert Udelsman MD¹, James A. Brink, MD¹, and Tobias Carling MD PhD²
Yale University School of Medicine, Departments of Diagnostic Radiology¹ and Surgery², 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

<table>
<thead>
<tr>
<th>ORGAN</th>
<th>Absorbed Dose (mGy)</th>
<th></th>
<th>ORGAN</th>
<th>Absorbed Dose (mGy)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SeS</td>
<td>4DCT</td>
<td></td>
<td>SeS</td>
<td>4DCT</td>
</tr>
<tr>
<td>Adrenals</td>
<td>3.2</td>
<td>0.8</td>
<td>Muscle</td>
<td>2.8</td>
<td>10.0</td>
</tr>
<tr>
<td>Brain</td>
<td>1.3</td>
<td>5.6</td>
<td>Ovaries</td>
<td>10.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Breasts</td>
<td>1.3</td>
<td>2.6</td>
<td>Pancreas</td>
<td>3.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Colon</td>
<td>33.0</td>
<td>0.0</td>
<td>Red Marrow</td>
<td>3.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Esophagus</td>
<td>1.7</td>
<td>27.2</td>
<td>Bone Surfaces</td>
<td>4.3</td>
<td>24.8</td>
</tr>
<tr>
<td>Gallbladder Wall</td>
<td>13.4</td>
<td>0.3</td>
<td>Skin</td>
<td>1.4</td>
<td>9.6</td>
</tr>
<tr>
<td>Small Intestine</td>
<td>20.1</td>
<td>0.0</td>
<td>Spleen</td>
<td>3.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Stomach</td>
<td>3.9</td>
<td>0.5</td>
<td>Thymus</td>
<td>1.7</td>
<td>27.2</td>
</tr>
<tr>
<td>Heart Wall</td>
<td>3.3</td>
<td>4.4</td>
<td>Thyroid</td>
<td>1.6</td>
<td>92.0</td>
</tr>
<tr>
<td>Kidneys</td>
<td>13.4</td>
<td>0.2</td>
<td>Urinary Bladder</td>
<td>27.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Liver</td>
<td>3.8</td>
<td>0.8</td>
<td>Wall</td>
<td>8.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Lungs</td>
<td>1.8</td>
<td>17.2</td>
<td>Uterus</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
## Combined Cancer Risk From 4DCT, SeS

<table>
<thead>
<tr>
<th>Age at Exposure (years)</th>
<th>Colon Cancers per 100,000 Persons Exposed</th>
<th>Thyroid Cancers per 100,000 Persons Exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>0</td>
<td>111</td>
<td>73</td>
</tr>
<tr>
<td>5</td>
<td>94</td>
<td>62</td>
</tr>
<tr>
<td>10</td>
<td>80</td>
<td>52</td>
</tr>
<tr>
<td>15</td>
<td>67</td>
<td>44</td>
</tr>
<tr>
<td>20</td>
<td>57</td>
<td>38</td>
</tr>
<tr>
<td>30</td>
<td>41</td>
<td>27</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
<td>26</td>
</tr>
<tr>
<td>50</td>
<td>37</td>
<td>24</td>
</tr>
<tr>
<td>60</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>70</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>80</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>
Outline

• Variation based on body habitus
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  Head / Neck  Chest / Cardiac
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  Integration with EMR
• > 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
**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
# NLST Low-Dose CT Technique

<table>
<thead>
<tr>
<th>Helical acquisition</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positioning</strong></td>
<td>Supine; arms elevated above the head</td>
</tr>
<tr>
<td><strong>Inspiration</strong></td>
<td>Suspended maximal</td>
</tr>
<tr>
<td><strong>Voltage (kVp)</strong></td>
<td>120–140</td>
</tr>
<tr>
<td><strong>Tube current–time product (mAs)</strong></td>
<td>40–80 (dependent on participant body habitus)</td>
</tr>
<tr>
<td><strong>Detector collimation (mm)</strong></td>
<td>≤2.5</td>
</tr>
<tr>
<td><strong>Nominal reconstructed section width (mm)</strong></td>
<td>1.0–3.2</td>
</tr>
<tr>
<td><strong>Reconstruction interval (mm)</strong></td>
<td>1.0–2.5</td>
</tr>
<tr>
<td><strong>Reconstruction algorithm</strong></td>
<td>Soft tissue or thin section</td>
</tr>
<tr>
<td><strong>Scanning time (sec)</strong></td>
<td>&lt;25</td>
</tr>
</tbody>
</table>
NSLT: $CTD_{vol}^{\text{mean}} = 2.9 \text{ mGy}$

## Cardiac CT

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

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
- X-ray on time
- Target Phase range
- 6-15 mSv

Prospective Gated Axial Acquisition
- Single phase or phase range
- Low dose acquisition
- Table move
- X-ray on time
- Target Phase range
- 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
CTDIsn = 21.6 mGy
Eff. Dose = 28 mSv

2009 – Prospective
Gating; 60% ASIR
CTDIsn = 6.8 mGy
Eff. Dose = 4.5 mSv
Siemens Dual Source Flash

SSCT Spiral

Scan 1
Scan 2
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:** \( DLP = 136 \text{ mGy-cm} \) (2.0 \( \text{mSv} \))

Noise: 23.2

ASIR 50% – Noise: 13.7
CT Colonography

NYU: Siemens 4DCT

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

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

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

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

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Decision Support

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

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

<table>
<thead>
<tr>
<th>Results:</th>
</tr>
</thead>
<tbody>
<tr>
<td>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 ($P &lt; .001$). 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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conclusion:</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

*Radiology 2009; 251: 147-155*
CT Utilization at MGH

# of CT scans ordered with CPOE/DS

*Radiology 2009; 251: 147-155*
PCP Practice Pattern Variation
MRI L Spine for low back pain

PCP MRI L-Spine Orders Per 1000 LBP Office Visits (Oct 07 - Jun 08)

Courtesy of
Ramin Khorasani, MD, MPH 2009
Appropriateness of L-Spine MRI for evaluation of low back pain by PCPs

Metric: Adherence to evidence-based guidelines

- Pre-Intervention: 42%
- Post-Intervention: >90%

P = <0.001
Image Wisely

Take the pledge

Pledge to image wisely by optimizing the use of radiation when imaging patients.

8022
PLEDGES TO DATE

September 18, 2011