CARDIAC CT ANGIOGRAPHY
RADIATION DOSE: HOW LOW CAN WE GO?

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USA MEDICAL RADIATION EXPOSURE:

- largest dose contributions are from CT & nuclear med studies (75% of collective effective dose)

Table 1. Estimated number and collective dose from various categories of radiographic and nuclear medicine procedures utilizing ionizing radiation (2006).^1

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of procedures (millions)</th>
<th>Collective dose (person-Sv)</th>
<th>Per capita dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>281</td>
<td>66 (100)</td>
<td>0.4</td>
</tr>
<tr>
<td>Interventional</td>
<td>62</td>
<td>167 (100)</td>
<td>0.4</td>
</tr>
<tr>
<td>CT</td>
<td>17</td>
<td>80 (100)</td>
<td>1.5</td>
</tr>
<tr>
<td>Nuclear medicine</td>
<td>79</td>
<td>23 (100)</td>
<td>0.3</td>
</tr>
<tr>
<td>Total</td>
<td>381</td>
<td>368 (100)</td>
<td>0.9</td>
</tr>
</tbody>
</table>

^1 Dental广大市民. Mammography (34.5 million) included in radiography.
^2 Numbers have been rounded.

USA MEDICAL RADIATION EXPOSURE

- 1982: per capita dose 0.54 mSv; collective dose 124,000 person-Sv
- 2006: per capita dose 3.0 mSv (600%); collective dose 900,000 person-Sv (700%)}

CT SCANNER AND MANUFACTURER TECHNOLOGY

GOAL

TO ACHIEVE OPTIMIZED MOTION-FREE IMAGING OF THE HEART AND CORONARY VESSELS FOLLOWING THE "ALARA" PRINCIPLE

USING AS LOW A DOSE AS REASONABLY ACHIEVABLE WHILE MAINTAINING DIAGNOSTIC IMAGE QUALITY

PARAMETERS INFLUENCING PATIENT DOSE

- Tube current
- Tube voltage
- Gantry rotation time
- Collimated detector slice width
- Z-coverage
- Beam pitch (helical acquisition)
- Image spacing (axial acquisition)

RADIATION DOSE IS PROPORTIONAL TO TUBE CURRENT, EXPOSURE TIME, AND THE SQUARE OF TUBE VOLTAGE AND IS INVERSELY PROPORTIONAL TO PITCH

TUBE CURRENT

- Radiation dose is proportional to tube current
- reflects the number of electrons flowing from the negative to the positive electrode in an X-ray tube
  - expressed in milliamperes (mA)
- increasing the X-ray tube current increases the number of electrons striking the target, resulting in a higher X-ray flux (the number of electrons produced per unit time).
  - resultant increase in photon penetration and patient dose

TUBE VOLTAGE

- Radiation dose is proportional to the square of the tube voltage
- increasing peak X-ray tube voltage increases the number and energy of X-rays produced
  - resulting in increased X-ray penetration and radiation exposure
- in addition to decreasing radiation dose, lowering the tube voltage results in decreased Compton scattering and increased photoelectric effect which increases vascular opacification

SCAN LENGTH

- Radiation dose is proportional to proscribed scan length
- the longer the scan length, the higher the patient dose

PITCH

- Radiation dose is inversely proportional to pitch
- for a spiral scan, pitch is the longitudinal distance in mm that the table travels during one rotation of the X-ray tube divided by the collimation of the x-ray beam
- decreasing the pitch results in increased overlap between data acquisitions
  - increases scan time and X-ray exposure

WHAT IS THE EFFECT OF CHANGING EACH PARAMETER?

- Decreasing tube current
  - decreases dose but increases image noise
- Decreasing voltage
  - decreases dose but increases image noise
- Faster gantry rotation time
  - improves temporal resolution but increases image noise
- Decreasing z-collimated detector slice width
  - improves z-axis spatial resolution but increases image noise
- Increasing Z-axis coverage per rotation
  - decreases scan time & # heartbeats but potentially increases exposure of tissue outside the desired imaging range (z-overscanning)
- Increasing pitch (helical acquisition)
  - decreases scan time; decreases dose
- Increasing image spacing (axial acquisition)
  - decreases scan overlap; decreases dose
**HOW DO WE DESCRIBE RADIATION DOSE??**

- CTDI<sub>vol</sub> (in Gy)
  - averages radiation dose over the x, y, & z directions
  - expresses the average dose to the scan volume for a CT exam
- Dose length product (DLP) in mGy x cm
  - = CTDI<sub>vol</sub> times scan length
  - indicates integrated radiation dose for the scan
- Effective dose (E) in mSv
  - reflects the varying radiosensitivity of the tissues within the acquisition
  - = DLP x chest conversion coefficient (k) where k = 0.014 mSv mGy⁻¹ cm⁻¹

**BASIC PILLARS OF DOSE REDUCTION**

- **Appropriate Utilization**
- **Dose Reduction Technology**

**APPROPRIATE UTILIZATION**

- Confirm the test is indicated
  - does it follow appropriateness guidelines
  - is there an appropriate risk/benefit ratio
  - will it change patient management
  - are there other tests that can give the same info with less or no radiation (ie MRI)

**APPROPRIATE PATIENT SELECTION & PREPARATION**

- is the patient able to cooperate & tolerate the scan
- is the patient body habitus appropriate for the scan and chosen protocol
- is there an appropriate heart rate/rhythm for scanner and protocol
- ?? beta-block

**VENDOR CT DOSE REDUCTION FEATURES**

- Adaptive pre-patient z-collimators
- Cardiac specific X-ray filters and X-ray beam shaping filters
- More efficient detector materials
- Automatic tube current adaptation along x, y, and z directions
- Automatic tube voltage adaptation
- Automated arrhythmia rejection methods
- postpone acquisition until stable HR

**AUTOMATIC TUBE VOLTAGE ADAPTATION PROSPECTIVE ECG - TRIGGERING**

- OFF
- ON
WHAT MANUAL ADJUSTMENTS CAN WE MAKE TO HELP MINIMIZE PATIENT DOSE???

PROTOCOL MODIFICATION FOR DOSE REDUCTION

- adjust number of series (based on clinical question)
- how many series are necessary?
- different protocol for follow up vs. initial workup?
- use small FOV (improves spatial resolution)
- adjust scan length
- adjust tube current and voltage
- adjust reconstruction method
- adjust type of EKG synchronization
- change type of reconstruction

PROTOCOL MODIFICATION FOR DOSE REDUCTION

- series adjustment (? clinical question)

SCAN LENGTH ADJUSTMENT

- Prospective gating with 320-MDCT

EKG SYNCHRONIZATION

- Retrospective gating
- Prospective triggering

RETROSPECTIVE ECG GATING

- ADVANTAGES:
  - spiral mode: volumetric data acquired thru whole cardiac cycle
  - data from specific parts of cardiac cycle retrospectively referenced to ECG signal for image recon
  - can perform LV functional analysis and 4D evaluation
  - less dependent on regular heart rhythm (capability to edit)
- DISADVANTAGE:
  - higher radiation dose (9-21 mSv)

* Khan, et al. AJR 2011; 196: 407-11

### PROSPECTIVE EKG TRIGGERING

**ADVANTAGES:**
- "step and shoot": predefined acquisition point in cardiac cycle
- significant dose reductions c/w retrospective gating
- 2-5 mSv

**DISADVANTAGES:**
- vulnerable to cardiac motion artifacts with high or irreg HRs
- not possible to perform accurate LV functional analysis

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**PROSPECTIVE GATING: 5 mSv**

LAD  
RCA

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**PADDING**

SSCT min current duration = \( \frac{1}{4} \) rotation time + fan <

45% increase in radiation dose for every 100-millisecond increase in padding

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**Comparison of Sequential and Helical Scanning for Radiation Dose and Image Quality: Results of the Prospective Multicenter Study on Radiation Dose Estimates of Cardiac CT Angiography (PROTECTION) Study**

- OBJECTIVES: Given the widespread use of the radiation exposure of cardiac CT angiography (CTA), a prospective multicenter study was conducted to evaluate radiation dose and image quality in patients undergoing CTA.

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**Radiation-Related Cancer Risks in a Clinical Patient Population Undergoing Cardiac CT**

- OBJECTIVE: To estimate the risk of radiation-induced cancer in patients undergoing cardiac CT.

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**How does this translate into cancer risk??**

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**Bischoff, et al. AJR 2010; 194: 1495-1499**

**Earls, et al. Radiology 2008; 246: 742-63**

**LaBounty, et al. AJR 2010; 194: 933-37**

**Huda, et al. AJR 2011; 196: W159-165**
RISK IS GREATER WITH YOUNGER AGE!!

Huda, et al.  AJR 2011; 196: W159-165

How does this translate into cancer risk??

50 year old subject LAR of cancer was calculated for retrospectively ECG-gated CTA to be 0.103% and 0.228% for US males and females, respectively.

For prospectively ECG-gated CTA, the corresponding values were calculated to be 0.013% and 0.036% for US males and females, respectively.

PROSPECTIVELY ECG-TRIGGERED HIGH-PITCH SPIRAL WITH DSCT

25 pts
Mean eff dose 1.0 mSv


HIGH PITCH SPIRAL DSCT

• HR slow and regular (<60 BPM)
• Non-obese patients

TUBE CURRENT ADJUSTMENT

PROTOCOL study:
every 100-mA tube current reduction was associated with a 20% reduction in radiation dose


ECG-GATED TUBE CURRENT MODULATION

* Irregular & variable HRs require widening of nominal dose window

Radiation dose is decreased up to 50% depending HR, minimum tube current, and duration of max current
EFFECT OF INCREASING HR ON ECG MODULATION

Low HR  
High HR

TUBE VOLTAGE ADJUSTMENT

- Radiation exposure = proportional to the square of the tube voltage
  - PROTECTION STUDIES: reducing from 120 to 100 kV results in 53% (PROTECTION I) and 31% (PROTECTION II) dose reduction but increases noise
  - Reducing tube voltage also affects tissue contrast
    - increases photoelectric effect and decreases Compton scattering
      - increased vascular opacification

- NYU BMI based protocols:
  - 120 kV for BMI > 30
  - 100 kV for BMI 23-30
  - 80 kV for BMI < 23

RECONSTRUCTION METHOD

- Filtered back projection (FBP)
- Iterative reconstruction
  - method varies per vendor
    - Adaptive statistical iterative reconstruction (ASIR) and model based (MBIR): GE
    - Iterative reconstruction in image space (IRIS) and Sinogram Affirmed Iterative Reconstruction (Safire): Siemens
    - Adaptive iterative dose reduction (IARD): Toshiba
    - i-Dose: Philips

ITERATIVE RECONSTRUCTION

- Assumes initial attenuation coefficients for all voxels and uses these coefficients to predict projection data
  - predicted projection data are compared to actual projection data and voxel attenuations are modified until the error between estimated and measured projection data is acceptable
- IR algorithms reduce image noise
  - thereby allowing tube current reduction
- Produce equivalent signal-to-noise ratios at lower radiation doses without loss of spatial resolution
- Require more time for image reconstruction than FBP
Estimated Radiation Dose Reduction Using Adaptive Statistical Iterative Reconstruction in Coronary CT Angiography: The ERASIR Study

OBJECTIVE. The objective of our study was to assess the impact of Adaptive Statistical Iterative Reconstruction (ASIR) on radiation dose and study quality for coronary CT angiography (CCTA).

SUBJECTS AND METHODS. We prospectively evaluated 27 consecutive patients undergoing coronary angiography with 64-slice multidetector CT (MDCT) (Siemens Definition Flash, Siemens, Erlangen, Germany). Patients were randomly assigned to the ASIR group (n = 13) with 50% ASIR, and the conventional FBP group (n = 14) with standard dose and test protocol. CT image noise was recorded as the standard deviation of the CT density in the region of interest (ROI).

RESULTS. There was no difference between groups in the use of prospective gating, table velocity, or scan length. Four consecutive patients performed using ASIR had elevated cardiac rates. Overall, the heart rate of the FBP group was significantly lower than that of the ASIR group (p < 0.01). The mean heart rate of the FBP group was 68.9 ± 15.8 beats per minute, whereas in the ASIR group it was 75.4 ± 17.6 beats per minute (p < 0.01). The mean radiation dose in the ASIR group was 72.5 ± 37.1 mSv, whereas it was 104.9 ± 39.6 mSv in the FBP group (p = 0.002). The image noise in the ASIR group was significantly lower than that in the FBP group (p < 0.001). No difference was noted in the dose-length product, which was 83.1 ± 38.4 mGy cm in both groups (p = 0.31).

CONCLUSION. ASIR enabled reduced tube current and lower radiation dose in comparison with FBP at comparable image quality and radiation dose, as well as improved cardiac rate control. ASIR may represent a new technique to reduce radiation dose in coronary CTA studies.


FBP IR

σ = 20.7

σ = 14.8

* Image noise = standard deviation of CT density in ROI

COMBINE DOSE REDUCTION TECHNIQUES WHEN APPROPRIATE

Radiation Dose From Cardiac Computed Tomography Before and After Implementation of Radiation Dose–Reduction Techniques

CCTA is the workhorse for noninvasive assessment of the coronary arteries and has become the standard of care for evaluating coronary artery disease. As the number of CT examinations has increased, the associated radiation dose has also increased. To address this issue, radiation dose reductions are needed. Recent technological advances in CT imaging, such as prospective triggering and lower tube current, have led to significant reductions in radiation dose. However, further reductions are still needed to meet regulatory requirements. This study evaluated the potential for combined dose reduction strategies in CCTA.

JAMA 2009; 301 (22): 2340-8

100 kV; PROSPECTIVE TRIGGERING: 2 mSv
80 kV; High Pitch Spiral DSCT: 0.7 mSv

62 yo man with chest pain; BMI 21

80 kV; High Pitch Spiral DSCT: 0.4 mSv

67 yo woman with chest pain; BMI 23; mean HR 61 BPM

80 kV; High Pitch Spiral DSCT: 0.2 mSv

14 yo boy with syncope after exercise; BMI 19

IN CONCLUSION.....
WHEN CONSIDERING DOSE REDUCTION WE SHOULD BEAR IN MIND THE WORDS OF LEONARDO Da VINCI

“I have been impressed with the urgency of doing. Knowing is not enough; we must apply. Being willing is not enough; we must do.”

-- Leonardo da Vinci