WHAT WE CAN LEARN FROM CURRENT CARDIAC CT TECHNOLOGY AND WHAT’S NEXT FOR CARDIAC?

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Oakland University William Beaumont Medical School
DISCLOSURES

• Research grant: Siemens
• I will be presenting state-of-the-art technology with slides graciously provided by
  • Philips
  • GE
  • Toshiba
  • Siemens
• I am responsible for all mistakes in describing these technologies, my only excuse being that I am only a humble clinician, not a physicist!
Achieving “Real-Life” Major Dose Reduction

- There has been a ~70% drop in the median radiation dose in the Michigan cardiac CTA quality improvement registry since 2007. This includes over 39,000 scans.
- Dose reduction depends not only on advancing technology but improving skills in using that technology, as well as monitoring dose and providing feedback.
- Future of dose reduction depends on:
  - Faster temporal resolution
  - Advanced detector technology
  - Automated dose reporting to quality improvement registries
Appropriate Indications for cardiac CTA

- Emergency or inpatient diagnosis of acute chest pain
- Outpatients with non-acute symptoms
  - After equivocal or nondiagnostic stress tests
  - Alternative to stress tests
  - Bypass and stent graft patency
  - Congenital heart disease
  - Pre-op planning for arrhythmia ablation and transcutaneous valve implants
**Objectives**

To determine whether a collaborative radiation dose-reduction program would be associated with reduced radiation dose in patients undergoing CCTA in a statewide registry over a 1-year period and to define its effect on image quality.

**Design, Setting, and Patients**

A prospective, controlled, nonrandomized study conducted during a control period (July-August 2007), an intervention period (September 2007-April 2008), and a follow-up period (May-June 2008) at 15 hospital imaging centers participating in the Advanced Cardiovascular Imaging Consortium in Michigan, which included small community hospitals and large academic medical centers. A total of 4995 sequential patients undergoing CCTA for suspected coronary artery disease were enrolled; 4862 patients (97.3%) had complete radiation data for analysis.
Results  Compared with the control period, patients' estimated median radiation dose in the follow-up period was reduced by 53.3% (dose-length product decreased from 1493 mGy × cm [interquartile range (IQR), 855-1823 mGy × cm] to 697 mGy × cm [IQR, 407-1163 mGy × cm]; P < .001) and effective dose from 21 mSv (IQR, 12-26 mSv) to 10 mSv (IQR, 6-16 mSv) (P < .001). The greatest reduction in dose occurred at low-volume sites.
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Further reductions 2008-2010

Progressive Radiation Dose Reduction from Coronary Computed Tomography Angiography in a Statewide Collaborative Quality Improvement Program: Results from the Advanced Cardiovascular Imaging Consortium (ACIC)


*William Beaumont Hospital, Cardiology Division, Royal Oak, MI, †Sarver Heart Center, College of Medicine University of Arizona, Tucson, AZ, ‡Department of Family Medicine, University of Michigan Health System

In review
2007-2011 Dose Reduction: 69%

Radiation (mSv)

1493 mGy-cm

468 mGy-cm
The KEY element

• The single most important element in reducing dose was providing sites with their “report card”.

• If a site’s median dose was considerably higher than average, it was tremendously motivated to get help to improve.
Case Study

- 71 yo female presented to the ER with several hours of chest pain
- Complex history: chronic atypical pneumonia, cough, peripheral venous disease
- EKG/cardiac enzymes non-diagnostic but nuclear stress testing positive
- Cardiac cath recommended but patient refused
- Cardiologist ordered “triple rule out” (TRO): full thorax CT angiography to simultaneously exclude coronary disease, pulmonary embolism and aortic dissection
- In the past, this triple procedure involved radiation doses of ~1700 mGy-cm and compromised image quality
Scan quality good – scan range excessive

PE study

Coronary study
Mild, non-obstructive coronary disease

No cath needed

Stress test was a false positive
Normal pulmonary angiogram. Focal emphysema, bilateral pulmonary nodules.
In the past TRO total dose ranged from 1200-1800 mGy-cm
In this case the total DLP = 389 mGy-cm
How was this achieved?
### CCTA Scan Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scanner Type</strong></td>
<td>Definition Flash</td>
</tr>
<tr>
<td><strong>Acquisition Type</strong></td>
<td>Adaptive Sequence</td>
</tr>
<tr>
<td><strong>Scan Length (cm)</strong></td>
<td>20</td>
</tr>
<tr>
<td><strong>kVp</strong></td>
<td>100</td>
</tr>
<tr>
<td><strong>mAs</strong></td>
<td>282</td>
</tr>
<tr>
<td><strong>Type of Gating</strong></td>
<td>Prospective</td>
</tr>
<tr>
<td><strong>Triple Rule-Out</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Dose Modulation (EKG Pulsing)</strong></td>
<td>No</td>
</tr>
<tr>
<td><strong>Other Dose Reduction Method</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Comment</strong></td>
<td>Flash pe, sequence heart, 100kv</td>
</tr>
<tr>
<td><strong>244 Radiation (Total DLP x 0.014)</strong></td>
<td>5.446</td>
</tr>
<tr>
<td><strong>Contrast Rate and Concentration</strong></td>
<td>Isovue 370</td>
</tr>
<tr>
<td><strong>Total Contrast Volume for CTA</strong></td>
<td>90</td>
</tr>
<tr>
<td><strong>Injection Rate (mL/ sec)</strong></td>
<td>6.0</td>
</tr>
<tr>
<td><strong>Specify CTA Image Recon</strong></td>
<td>Multiple</td>
</tr>
<tr>
<td><strong>Stent</strong></td>
<td>No</td>
</tr>
<tr>
<td><strong>CABG</strong></td>
<td>No</td>
</tr>
<tr>
<td><strong>Dye Allergy Prep</strong></td>
<td>No</td>
</tr>
<tr>
<td><strong>Dye Allergy Antihistamines</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Dye Allergy Steroids</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Patient’s Rhythm during Scan</strong></td>
<td>Sinus Rhythm</td>
</tr>
<tr>
<td><strong>Average HR during CTA</strong></td>
<td>58</td>
</tr>
<tr>
<td><strong>Beta Blockers</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Beta Blocker Delivery</strong></td>
<td>Oral Comments: 25mg Metoprolol</td>
</tr>
<tr>
<td><strong>Sublingual NTG</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td>15</td>
</tr>
<tr>
<td><strong>Multiphase Recon</strong></td>
<td>Yes</td>
</tr>
</tbody>
</table>
Specific dose reduction in this case

1. 100 kV tube potential
2. “care-dose” active mA adjustment from topogram
3. High-pitch spiral PE protocol: cranial-caudal followed by
4. Sequential CCTA protocol: caudal-cranial
5. Iterative recon level 2 with 20% mA reduction
6. We will review each of these methods in detail
Best-practice use of technology available in 2011

SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT

Sandra S. Halliburton, PhD, Suhy Abbara, MD, Marcus Y. Chen, MD, Ralph Gentry, RT(R) (MR) (CT), Mahadevappa Mahesh, MS, PhD, Gilbert L. Raff, MD, Leslee J. Shaw, PhD, Jorg Hausleier, MD

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Instructions to the referring physician

• Be specific about the clinical question
• Counsel and prep the patient in advance
• Consult with imaging MD if desired
• All this is vital because the exam may define the protocol and rad dose:
  – e.g., If pulmonary veins are all that is required, coronary protocol is not necessary and very low dose protocol can be done without beta blockers.
Protocol variations by clinical questions

- Congenital heart disease – coronaries rarely diseased, can use aggressive low dose protocols
- Preoperative pulmonary vein ablation – also very low dose protocols
- Triple rule-out (CAD, PE, Ao) exams increase dose due to larger field of view. Recent advances minimize the problem
- Transcutaneous valve planning very high dose unless the field of view is minimized for the valve and high-pitch (or wide detector array) scanning is used for thorax-abdomen-pelvis runoff
Instructions to the patient

• Do not use caffeine but take plenty of fluids
• Take usual medications
• Be prepared with names of medicines, medical conditions, allergies
• Understand:
  – Will be receiving radiation
  – Will be receiving contrast
  – Will need to hold still and hold breath
  – These all prevent wasted need for repeat studies
Evaluation and preparation of PTs

- Nurse assesses baseline vital signs: HR, BP, rhythm, BMI
- If heart rate low (<65) use a handgrip stress to define acceleration
- Proceed to exam only if target heart rate met
- Baseline dose of beta blocker usually 100 mg (metoprolol). This is larger than used in many beginning centers, resulting in image artifacts and repeat exams.
- Call MD for additional measures if not at target
- Communicate with technologists about difficult patients
- MDs MUST be available for collaboration!
Patient-specific parameters

- Because dose increases with the square of the tube potential, this is the single most important factor in adjusting patient-specific parameters.
- Body mass index (BMI) determines the kVp required to avoid severe noise. Simple height and weight charts are used to specify kVp = 120, 100 or 80.
- U.S. patients tend to be more obese: half the cardiac patients have BMI > 30 and require 120 kVp.
- Unfortunately patients with BMI >40 (morbid obesity) often have no alternatives to CTA and require kVp of 140 and high dose protocols.
- There is no simple way to adjust tube current by BMI, but engineered current modulation from topogram is commonly available.
Coronary CT Angiography

STATEGIES TO LIMIT EXPOSURE

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Slides in blue courtesy of
Dr Stephen Achenbach
Keynote lecture SCCT 2011
STATEGIES TO LIMIT EXPOSURE*

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STATEGIES TO LIMIT EXPOSURE

1. Beyond the time necessary to reconstruct an image, irradiate as short a segment of the cardiac cycle as possible

2. Use less photons per cross-sectional image
Scan Protocols

SPIRAL/HELICAL Scan  „ECG pulsing“ – 40 to 50% reduction of dose
Scan Protocols

SPIRAL/HELICAL Scan

„ECG pulsing“ – 40 to 50% reduction of dose
Scan Protocols

PROSPECTIVELY TRIGGERED SCAN

- 64 slice: ~ 6-8 steps
- 128 slice: ~ 3-4 steps
- 256 slice: ~ 2 steps
- 320 slice: ~ 1 step
Scan Protocols

PROSPECTIVELY TRIGGERED SCAN

“Padding“
Recommendations

Prospective ECG-triggered axial techniques should be used in patients who have stable sinus rhythm and low heart rates (typically <60–65 beats/min, but specific values depend on specific scanner characteristics and cardiovascular indication).

For prospective ECG-triggered axial techniques, the width of the data acquisition window should be kept at a minimum.
“Prospectively Triggered High Pitch Spiral“
Low Dose Cardiovascular CT for All Patients

- Single Rotation 64 detector row CT coverage: 4 cm
- Single Rotation 128 detector row CT coverage: 8 cm
- Single Rotation 320 detector row CT coverage: 16 cm
### “Dial a Dose”

<table>
<thead>
<tr>
<th>Technique</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 kV</td>
<td>~ 25 mSv</td>
</tr>
<tr>
<td>Spiral, No pulsing</td>
<td>~ 13 mSv</td>
</tr>
<tr>
<td>Spiral, Pulsing</td>
<td>~ 5 mSv</td>
</tr>
<tr>
<td>Spiral, Aggressive Pulsing</td>
<td>~ 3 mSv</td>
</tr>
<tr>
<td>Prospective Trigger</td>
<td>~ 1.4 mSv</td>
</tr>
<tr>
<td>High Pitch Spiral</td>
<td></td>
</tr>
</tbody>
</table>
Less Photons per Image

- **Tube voltage** (tube potential)
- **Tube current**

Linear to dose

\[
\frac{1}{\sqrt{\text{noise}}} : 20\% \text{ reduction of tube current} \Rightarrow 12\% \text{ increase in noise}
\]
Photons per Image –

Less Photons per Image

- Tube voltage (potential)
- Tube current

Linear to dose

$1/\sqrt{\text{noise}}$: 20% reduction of tube current => 12% increase in noise

Recommendations

The scanner default tube current values should be adjusted, based on each individual patient’s size and clinical indication, to the lowest setting that achieves acceptable image noise.
**Tube Voltage**

**When to use 100 kV tube current?**

- < 85 kg (Gopal et al, Int J Cardiovasc Imag 2009)
- BMI < 25 kg/m² (Herzog et al, Acad Radiol 2009)
- BMI < 30 kg/m² (LaBounty et al, Am J Cardiol 2010)
- < 85 kg and BMI < 30 kg/m² (Raff et al, JAMA 2009)
- < 90 kg or BMI < 30 kg/m² (Hausleiter et al, JACC Img 2010)
- < 100 kg (+ tech eyeball)
**Dose by protocol**

<table>
<thead>
<tr>
<th>Protocol</th>
<th>120kV</th>
<th>100 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral, No pulsing</td>
<td>~ 25 mSv</td>
<td>~ 18 mSv</td>
</tr>
<tr>
<td>Spiral, Pulsing</td>
<td>~13 mSv</td>
<td>~ 9 mSv</td>
</tr>
<tr>
<td>Spiral, Aggressive Pulsing</td>
<td>~ 5 mSv</td>
<td>~ 3 mSv</td>
</tr>
<tr>
<td>Prospective Trigger</td>
<td>~3 mSv</td>
<td>~ 2 mSv</td>
</tr>
<tr>
<td>High Pitch Spiral (&quot;Flash&quot;)</td>
<td>~ 1.4 mSv</td>
<td>~ 0.9 mSv</td>
</tr>
</tbody>
</table>
Tube Voltage

120 kV vs. 120 kV:
31% reduction of dose
20% increase in noise
Iterative Reconstruction

“Iterative Reconstruction“

“IRIS“ - “ASIR“ - “ADIR“ - “iDose“

Standard  Iterative Reconstruction
N = 50
Dose = 0.76 mSv
Sensitivity 100%
Specificity 82%

Detection of Coronary Artery Stenoses by Low-Dose, Prospectively ECG-Triggered, High-Pitch Spiral Coronary CT Angiography

Stephan Achenbach, MD,* Tobias Goroll,* Martin Seltmann, MD,* Tobias Pflederer, MD,* Katharina Anders, MD,† Dieter Ropers, MD,* Werner G. Daniel, MD,* Michael Uder, MD,† Michael Lell, MD,† Mohamed Marwan, MD†
“Sub mSv”

80 kV

57 kg

Prospective trigger

0.58 mSv
Reducing Dose Throughout the Imaging Chain
Quality, Quantity and Where Needed: At the point of creating x-rays

**SmartShape:** Increase beam hardness and reduce soft radiation when possible

**IntelliBeam Filters:** Shapes the beam intensity based on object size

**Eclipse DoseRight Collimator:** Blocks unnecessary “over-ranging” at the start and end of all helical scans
Reducing Dose Throughout the Imaging Chain

Quality, Quantity and Where Needed: At the point of detecting x-rays

**NanoPanel Detector:** Reduced electronic noise. 86% improvement over conventional electronics

**ClearRay Collimator:** Reduces scatter artifact and nonuniformity. 3x improved scatter to primary ratio (SPR)

**Spherical Detector:** Geometry for true cone-beam focus.
Optimizing Image Quality Throughout the Chain

Quality, Quantity and Where Needed: At the point of *creating images*

**ClearRay Reconstruction:** Reduces beam hardening and scatter artifacts. Improved homogeneity of HU and sharpness of organs.

**iDose⁴ Iterative Reconstruction Technique:** Improve image quality, Preserve “natural” appearance, Robust artifact prevention, and Fast reconstruction speed.
Novel detector technology

**CT750 HD**

**GE Gemstone Scintillator**
- Gemstone preserves all HiLight™ benefits
- 100 times faster... enables next generation Spectral Imaging

Garnet chosen for its highly efficient optical properties. Examples
- Surgical lasers
- HID (Xenon) headlights
Stellar Detector
Highly integrated design with full electronic integration

### Conventional Detector
- Conventional photodiode (PD)
- Complex board w/ AD-converters
  - Discrete PD and AD-converters
  - High number of electronic parts
  - Long elec. connection distance
  - Typical elec. noise contribution

### Fully Integrated Stellar Detector
- Photodiode and AD-converters in one ASIC
- Simple board w/o AD-converters
  - Integrated PD and AD-converters in one ASIC
  - Virtually no connection distance
  - Significantly reduced elec. noise

AD: Analog-to-Digital-Converter // ASIC: Application Specific Integrated Circuit
**Stellar Detector**

Minimizing cross-talk is key

---

**X-Ray**

**z-direction**

**septa**

**aperture**

0.5 mm

0.6 mm

**Detector signal (ideal)**

**cross-talk**
Stellar Detector with Edge Technology
Physical proof of high resolution cross-plane imaging

Standard Detector

0.6 mm slice
B70

0.69 mm FWHM

Disc Phantom

16.4 lp
z-MTF rho₂

New Stellar Detector

0.6 mm slice
B70

0.48 mm FWHM

Disc Phantom

18.5 lp
z-MTF rho₂

MTF: Modulation Transfer Function // FWHM: Full width at Half Maximum
**Stellar Detector**
Minimized electronic noise

**Conventional detector**

- **High signal:** small patient, high dose
- **Low signal:** large patient, low dose

Streaks due to electronic noise

Courtesy of Dr. J. Hausleiter, MD, Cardiologist, German heart center, Munich, Germany
Stellar Detector
Minimized electronic noise

Conventional detector

Stellar Detector

No streaks

High signal:
small patient
high dose

Low signal:
large patient
low dose

 Courtesy of Dr. J. Hausleiter, MD, Cardiologist, German heart center, Munich, Germany
## Stellar Detector
Analogy for HiDynamics with TrueSignal Technology

<table>
<thead>
<tr>
<th>Conventional Detector</th>
<th>New Stellar Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Limited dynamic range</td>
<td>▪ Full dynamic range</td>
</tr>
<tr>
<td>▪ Potential detail loss</td>
<td>▪ Higher image detail</td>
</tr>
</tbody>
</table>
AIDR 3D Algorithm

Acquired Projection Data → Scanner Model → Projection Noise Reduction → Statistical Model → Anatomical Model Based Optimization → Update Object → Blending % → AIDR Image

Adaptive → Iterative → Reduction

AIDR 3D Algorithm
GE “VEO” and Siemens “SAFIRE”: raw data IR technology
Cardiac: Effective Dose 0.4 mSv

Without AIDR 3D

With AIDR 3D

Courtesy Monash Medical Center, Melbourne, Australia
Performix™ HD Tube
Increased spatial resolution and spectral imaging

Dynamic Focal Spot Control
Increased data sampling
Ultra-Fast kVp Switching
Power on Demand
Maximum Power: 835mA
Up to 570mA on smallest spot
Heat storage capacity: 8 MHU

3 mm Stent
Non-HDCT CT750 HD
HD Fast Switching Generator

Powerful and Ultra Fast

100KW

10mA to 835mA for imaging patients of all sizes

Sub msec kVp switching dual energy imaging with a single tube.

As fast as a blink of an eye
Discovery CT750 HD FREEdom Edition
World’s first cardiac spectral CT

Motion FREEdom
Intelligent motion correction
SnapShot Freeze

Calculated FREEdom
Enhanced coronary visualization GSI Cardiac

Horizon FREE
Plaque material composition assessment
Accurate perfusion calculations
Preparing you for the future

*GSI is delivered with a base set of materials from the NIST database and is engineered for the capability to add other material from this database. Currently, HAP is not included on the scanner/viewer as one of the materials, but can be loaded by the user following instructions in the GSI Viewer User Manual.
Why don’t we achieve <1 mSv scans in practice?

• Most sites do not have new scanners incorporating all new technology
• Even in sites that do, it is very difficult to achieve stable HR <50 bpm in a large volume of typical patients
• The RCA lies on the right atrium, which moves during diastole. This frequently leads to motion artifacts; MDs are reluctant to use single beat acquisition for that reason
• Patients in these studies were imaged with 80 kVp. Our pts are not suitable due to high BMI. Noise levels are too high even with IR.
What is in the future for low dose cardiac CT?

- Key #1 to achieving lower doses: faster temporal resolution.
- This would permit use of single heartbeat protocols in more pts.
- Increasing detector sensitivity could reduce # of photons needed.
- With further reconstruction improvements expect better image quality/photon energy.
- Expect routine doses of <70 mGy-cm (<1 mSv) median within 5 yrs. That would be an 80% reduction from today.
The Last Word

We need an automated dose monitoring and reporting registry.

An imaging center cannot improve if they don’t know there is a problem.

Thank you for your attention!