Low Dose Era in Cardiac CT

DIANA E. LITMANOVICH, MD

Department of Radiology
Beth Israel Deaconess Medical Center
Harvard Medical School
Disclosures

Neither I nor my immediate family members have a financial relationship with a commercial organization that may have a direct or indirect interest in this content.
Radiation exposure in CCT: Moving target

Estimated radiation dose (mSv)

15mSv

9mSv

6mSv

2.3mSv

2mSv

1.9mSv

0.9mSv

And lower?

Small et al.; J Nuc Cardiol 2011
3 questions to be answered:

• What makes low dose cardiac CT possible?
• How low can we go?
• What are additional applications of low dose techniques?
Q1. What makes low dose cardiac CT possible?

Let's not forget the basic: 15 mSv \rightarrow \approx 5 \text{ mSv}

- Appropriate Z-axis selection
- Retrospective ECG-gating with aggressive tube current modulation and vigorous control of HR and rhythm
- BMI based mA: from 750 to < 300
- BMI based kVp: from 140 to 100 kVp
- Prospective ECG-gating
Scan coverage (Z) optimization

25 cm

12 - 14 cm

6.5 mSv vs. 3.46 mSv

40 mm - 45% in mSv

Khan et al.; AJR 2011
ECG-based Tube Current Modulation

Retrospective ECG - gating

- Dose modulation decreases radiation dose by >50%

- Lower HR increases the duration of low dose phase with additional drop in radiation dose
Anatomy-based tube current adaptation

Maximum mA selection based on BMI/weight

Effect of a Standardized Quality-Improvement Protocol on Radiation Dose in Coronary Computed Tomographic Angiography

Troy M. LaBounty, MD\textsuperscript{a}  James P. Earls, MD\textsuperscript{c}  Jonathon Leipsic, MD\textsuperscript{d}  Brett Heilbron, MD\textsuperscript{d}  G.B. John Mancini, MD\textsuperscript{d}  Fay Y. Lin, MD, MA\textsuperscript{a}  Allison M. Dunning, MSc\textsuperscript{a}  James K. Min, MD\textsuperscript{a,b}

Decrease in current: by 100 mA: ↓ 25% radiation dose
BMI based kVp

PROTECTION II:
400 patients, randomized trial 120 vs. 100 kVp
Stable sinus rhythm
< 90 kg, BMI < 30 kg/m²

↓ 31% in radiation dose

Hausleiter et al.; JACC 2010
Prospective ECG – gating: Axial scanning

Prospective ECG-Gated Scanning
Periodic table movement (Step)
X-ray tube ‘on’ intermittently (Shoot)

Step and shoot: Tube on in diastasis, tube switched off in remainder of cardiac cycle

Modifiable Factor: Tube on time

Table Move →

Preferred for pts with regular HR < 65 bpm
Prospective vs. Retrospective gating: Radiation comparison

↓ 77% in radiation dose

Shuman et al.; Radiology 2008
Prospective vs. Retrospective Technique: Radiation and Quality comparison

PROTECTION III

CONCLUSIONS In patients with stable and low heart rates, the prospectively ECG-triggered axial scan protocol maintained image quality but reduced radiation exposure by 69% compared with helical scanning. Axial computed tomography data acquisition should be strongly recommended in suitable patients to avoid unnecessarily high radiation exposure. (Prospective Randomized Trial on Radiation Dose Estimates of CT Angiography in Patients Scanned With a Sequential Scan Protocol [PROTECTION-III]; NCT00612092) (J Am Coll Cardiol Img 2012;5:484–93) © 2012 by the American College of Cardiology Foundation

Hausleiter et al.; JACC 2012
Prospective ECG – gating: Padding

- Padding varies from 0% to 100%
- 45% ↑ Radiation dose for each 100msec ↑ padding
- Functional evaluation: simultaneous image reconstruction in S and D

Radiation dose < than in retrospective ECG gating

LaBounty et al.; AJR 2010
Small et al.; J Nuc Cardiol 2011
**Advanced arrhythmia rejection algorithms:**

- Can only be done with prospective ECG gating
  - Stops data acquisition if extra systole
  - Resumes at the same z-position in the next regular heart cycle

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Coronary computed tomography angiography during arrhythmia: Radiation dose reduction with prospectively ECG-triggered axial and retrospectively ECG-gated helical 128-slice dual-source CT.


- ED 4.3 mSv vs. 9.1 mSv
  - >50% dose saving with similar image quality
Q1. What makes low dose cardiac CT possible?

Advanced methods in Cardiac CT: 5 mSv → <1 mSv

- Volumetric CT – 256, 320 wide detector arrays
- Dual Source CT High Pitch Flash mode
- Low kVp in non-obese and obese patients
- Automatic kVp selection
- Iterative reconstructions
Volumetric CT

- 320 x 0.5 collimation (1, 2, 3 generations)
- 256 x 0.625-mm collimation
- 16 cm axial data acquisition
- Entire heart is covered in one rotation (volume)
Volumetric CT

- 1st generation, 350 msec gantry rotation time
- HR < 65: 1 segment = 1 heart beat acquisition ≈ 4 mSv
- HR > 65: Multiple segments/multiple heart beats acquisition →↑ radiation dose (up to double!)

Khan et al.; AJR 2010
**Volumetric CT**

- 2\textsuperscript{nd}, 3\textsuperscript{rd} generation: 275 msec
- Wide range HR with prospective triggering with single-heart-beat CCTA in vast majority of patients, \(\approx\) HR 75 bpm
- Wide range of BMI with 100 kVp due to a large x-ray power generator (up to 900 mA)

< 0.93 mSv in 54%, < 4 mSv in 96%
Fast non-overlapping spiral data acquisition
Temporal resolution < 70 msec per image
Pitch >3.2, table speed up to 737 mm/sec, 1 heart beat < 1 mSv in patients with HR≤75
Dual-Source CT: 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd} generations

Radiation Dose at Coronary CT Angiography: Second-Generation Dual-Source CT Versus Single-Source 64-MDCT and First-Generation Dual-Source CT

Christian Fink\textsuperscript{1,2}
Radko Krissak\textsuperscript{2}
Thomas Henzler\textsuperscript{2}
Ursula Lechel\textsuperscript{3}
Gunnar Brix\textsuperscript{3}
Richard A. P. Takx\textsuperscript{1}
John W. Nance\textsuperscript{1}
Joseph A. Abro\textsuperscript{1}
Stefan O. Schoenberg\textsuperscript{2}
U. Joseph Schoepf\textsuperscript{1}

OBJECTIVE. The purpose of this study was to assess the radiation doses of different coronary CTA (CTA) protocols: second-generation dual-source 128-MDCT, first-generation dual-source 64-MDCT, and single-source 64-MDCT.

MATERIALS AND METHODS. Thermoluminescent dosimetry was used to determine scanner-specific dose coefficients for standard coronary CTA of an anthropomorphic phantom. These coefficients were used to estimate the effective doses (EDs) of retrospectively gated, prospectively triggered, and prospectively triggered high pitch coronary CTA performed at 100 and 120 kV. The coronary CTA protocols used in imaging of 43 patients undergoing dual-source 128-MDCT were analyzed for ED, image quality, and signal-to-noise ratio.

RESULTS. Regardless of coronary CTA protocol and CT system, imaging at 100 kV lowered the ED 40–50%. In retrospectively gated 120-kV coronary CTA, the ED ranged from 5.7 to 10.7 mSv and was approximately 50% lower with single-source 64-MDCT than with either DSCT protocol. In prospectively triggered 120-kV coronary CTA, the ED ranged from 3.8 to 4.0 mSv. The lowest ED of all protocols (1.3 mSv) was observed in prospectively triggered high-pitch 100-kV coronary CTA performed with dual-source 128-MDCT. Patient measurements showed similar dose reductions for prospective triggering and low voltage settings without an influence on signal-to-noise ratio or image quality.

CONCLUSION. A combination of prospective triggering with low voltage settings is an effective measure for reducing the ED of coronary CTA to values of 2–4 mSv independent of scanner system. Further dose reduction to nearly 1 mSv can be achieved with high-pitch prospectively triggered coronary CTA.

Keywords: coronary angiography, CT, phantom study, radiation exposure
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New era in kVp

• Standard approach:
  - BMI < 25  80 kVp
  - BMI < 25 – 30  100 kVp
  - BMI 30 – 35  120 kVp
  - BMI > 35  140 kVp

• New x-ray tube design in 3rd generation DSCT:
  - 70 kVp in BMI ≤ 28

• Coronary CT at 70-80 kVp in obese patients
  (phantom study)
Automatic Tube potential selection

- Applicable in both SSCT and DSCT
- Radiation Dose Estimates

2\textsuperscript{nd} generation DSCT
Mean CTDI\textsubscript{vol}: ↓30\% in study group compared with matched control group (BMI derived kVp selection)

Ghoshhajra et al., JTI 2013
Suh et al. Radiology 2013
Iterative reconstructions:

- Noise and artifacts reduction techniques
- $\uparrow$ SNR (objective) and $\uparrow$ image quality (subjective)
- Indirect contributor to dose reduction efforts
- ASiR, IRIS/SAFIRE, iDiose4, MBIR, AIDR
- Can be applied with wide range of kVp and mA
Iterative Reconstruction Algorithms

**Estimated Radiation Dose Reduction Using Adaptive Statistical Iterative Reconstruction in Coronary CT Angiography: The ERASIR Study**

**CCTA**: decrease in radiation dose by **44%**

BMI 22 kg/m² 100 kV, 325 mA, no padding, 14 cm: 0.56 mSv

*Leipsic et al.; AJR 2010*
Detection of coronary artery stenosis with sub-milliSievert radiation dose by prospectively ECG-triggered high-pitch spiral CT angiography and iterative reconstruction

- **2\textsuperscript{nd}** generation DSCT
- kVp 80 - 120; mAs 160-200; IR
- ED 0.58 ± 0.17 mSv, high diagnostic accuracy

Yin et al.; Eur Radiol 2013
What makes low dose cardiac CT possible?

Advanced methods in Cardiac CT: 5 mSv → <1 mSv

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- Dual Source CT High Pitch Flash mode
- Low kVp in non-obese and obese patients
- Iterative reconstructions

Combination of the above!
What makes low dose cardiac CT possible?

Meinel et al.; Circulation 2014
Q2: How low can we go?

3 representative studies:

Image quality of ultra-low radiation exposure coronary CT angiography with an effective dose <0.1 mSv using high-pitch spiral acquisition and raw data-based iterative reconstruction

80 kVp, 50 mAs, DSCT, IR BMI <26, HR 50 bpm

ED: $0.06 \pm 0.01$ mSv

Schuhbaeck et al.; Eur Rad 2013
Q2: How low can we go?

Image quality, radiation dose, and diagnostic accuracy of prospectively ECG-triggered high-pitch coronary CT angiography at 70 kVp in a clinical setting: comparison with invasive coronary angiography

70 kVp, 370 mAs, DSCT, IR, BMI <29, HR 69 bpm

ED: 0.02 ± 0.01 mSv

Zhang et al.; Eur Rad 2015
Q2: How low can we go?

Coronary CT Angiography at 100, 80, and 70 kV—Initial Comparison of a Second- versus a Third-Generation Dual-Source CT System

70 kVp, 570 mAs, DSCT, IR, BMI <25, HR 71 bpm

ED: $0.44 \pm 0.12$ mSv

SNR >> with 70 kVp compared to 80 and 100 kVp

ED 0.21 mSv

Meyer et al.; Radiology 2014
Q3. Additional applications of low dose techniques

- Calcium score CT
  High pitch DSCT with 120 kVp and 80 mAs: 0.3 mSv
  *Marwan et al. JCCT 2013*

- Dynamic perfusion CT
  DSCT, 80-100 kVp
  AEC
  ED < 5 mSv

*Kim SM. et al.; Int Journal of Cardiovasc Imag 2014*
Q3. Additional applications of low dose techniques

- TAVR assessment
  DSCT: 277 ± 100 mGy  aorto-iliac access assessment
  ED < 4 mSv

If DSCT for aortic valve: additional reduction

Harris et al.; Radiology 2015
Q3. Additional applications of low dose techniques

- Triple Rule Out
  Historically: >15 mSv
  Now: DSCT high-pitch, kVp 80-100, mAs < 350
  ED < 2 mSv

1.04 mSv
1.99 mSv
Q3. Additional applications of low dose techniques

Pediatric Cardiac CT

Image quality of ultra-low-dose dual-source CT angiography using high-pitch spiral acquisition and iterative reconstruction in young children with congenital heart disease

DSCT, kVp 80, 20-70 mAs ED 0.06-0.13 mSv

Zheng et al. JCCT 2013
Radiation exposure in CCT: Moving target

And lower?

Small et al. J Nuc Cardiol 2011
Summary

- Major impact on radiation dose reduction:
  - High pitch DSCT, volumetric MDCT
  - Automatic kVp selection
  - Increased tube power: Low kVp in wider population
  - Iterative reconstructions
- Sub 1 mSv can be achieved in clinical practice
- Wide spectrum of application in various cardiovascular imaging protocols
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