Low-dose coronary computed tomography angiography

Jörg Hausleiter

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Disclosure

Siemens Medical Solutions:
• Unrestricted research grants
• Speaker honoraria
Coronary CT Imaging Today
ECG-Gated Spiral CT Data Acquisition
Methods

PROTECTION I

- Study design: prospective, observational multi-center multi-vendor industry-independent


- 50 participating study sites
  1965 CCTAs

- Image data, patient and scan information of all consecutive ECG-gated or -triggered CCTAs performed during one month
CCTA Radiation Dose

PROTECTION I

Hausleiter et al.; JAMA 2009
Predictors of Radiation Dose

PROTECTION I

- Weight (↑10kg)
- Heart rhythm (non-sinus vs. sinus)
- Site experience (↑1yr)
- CCTA frequency (↑10 CCTA)

CT systems:
- 64-slice system 1
- 64-slice system 2
- 64-slice system 3
- 64-slice system 4
- 64-slice system 5

Scan length (↑1cm)
- ECG-controlled TCM
- Tube potential (100 vs. 120 kV)
- Axial scanning

Change (%) in dose-length-product
Reduced tube potential of 100 kV

PROTECTION II

Axial slice

120 kV

100 kV

Curved MIP of RCA
Methods
PROTECTION II

400 non-obese patients

randomization

202 patients
100 kVp CCTA
image quality & radiation dose
30-day follow-up

198 patients
120 kVp CCTA
image quality & radiation dose
30-day follow-up

study design: non-inferiority international multi-center multi-vendor
Methods
PROTECTION II

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Score 1: **non-diagnostic:** Poor image quality that precludes appropriate evaluation of the coronary artery.

Score 2: **adequate:** Reduced image quality because of artifacts, but still sufficient to rule out significant stenosis.

Score 3: **good:** Image quality with minor artifacts but allowing the assessment of luminal stenosis, calcified and non-calcified plaques.

Score 4: **excellent:** Absence of any artifacts, clear delineation of vessel walls, with the ability to assess luminal stenosis as well as plaque characteristics.
PROTECTION II – 100 kVp

Primary study endpoint

Image quality score

- 100 kVp: 3.30
- 120 kVp: 3.28

P = 0.742

Estimated radiation dose (mSv)

- 100 kVp: 8.4
- 120 kVp: 12.2

P < 0.0001
PROTECTION II – 100 kVp

Primary study endpoint

Image quality score

All P=n.s.

Estimated radiation dose (mSv)

All P<0.0001

GE  Siemens  Toshiba

GE  Siemens  Toshiba

100 kVp

120 kVp
ECG-Triggered Axial Scan Technique

70%  70%  70%  70%  70%
Axial Scan Technique
PROTECTION III

axial scan technique

spiral scan technique
Methods
PROTECTION III

400 patients

randomization

200 patients

axial CCTA

image quality & radiation dose

30-day follow-up

study design: non-inferiority international multi-center multi-vendor

200 patients

spiral CCTA

image quality & radiation dose

30-day follow-up
Methods
PROTECTION III

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PROTECTION III - axial
Primary study endpoint

Image quality score

P = 0.866

3.36  3.37

Estimated radiation dose (mSv)

P < 0.0001

3.5  11.2

axial

spiral
PROTECTION III - axial
Primary study endpoint

Image quality score

<table>
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<tr>
<th></th>
<th>GE</th>
<th>Philips</th>
<th>Siemens</th>
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<tr>
<td>sequential</td>
<td>3.22</td>
<td>3.38</td>
<td>3.47</td>
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<tr>
<td>spiral</td>
<td>3.00</td>
<td>3.57</td>
<td>3.52</td>
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Estimated radiation dose (mSv)

<table>
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<tr>
<th></th>
<th>GE</th>
<th>Philips</th>
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</tr>
</thead>
<tbody>
<tr>
<td>sequential</td>
<td>4.2</td>
<td>3.6</td>
<td>2.9</td>
</tr>
<tr>
<td>spiral</td>
<td>15.4</td>
<td>11.1</td>
<td>7.3</td>
</tr>
</tbody>
</table>
High-pitch spiral scan in dual-source CT
High Pitch Spiral Flash Scan

Definition Flash:
- 50 patients
- Mean CCTA dose: 0.9 ± 0.1 mSv

Achenbach, Marwan et al.; Eur Heart J 2009
Rationale

to determine the effect of a high-pitch first scan strategy on:

(1) image quality and

(2) total radiation dose

when compared with a conventional (axial or spiral low pitch) scan strategy for CCTA.
Methods

303 patients

randomization

150 patients
High-pitch first CCTA
image quality & radiation dose
30-day follow-up

153 patients
Conventional first CCTA
image quality & radiation dose
30-day follow-up

study design: non-inferiority international multi-center single-vendor
Methods
PROTECTION IV

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## Patient & Scan Characteristics

<table>
<thead>
<tr>
<th></th>
<th>High-Pitch (n=150)</th>
<th>Conventional (n=153)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient height, m</td>
<td>1.72 ± 0.09</td>
<td>1.73 ± 0.09</td>
<td>0.949</td>
</tr>
<tr>
<td>Patient weight, kg</td>
<td>77.9 ± 13.2</td>
<td>79.9 ± 14.7</td>
<td>0.223</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>55.5 ± 5.0</td>
<td>56.2 ± 5.7</td>
<td>0.259</td>
</tr>
<tr>
<td>Scan length, mm</td>
<td>127 ± 14</td>
<td>133 ± 15</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Repeat scan, n (%)</td>
<td>20 (13.3)</td>
<td>12 (7.8)</td>
<td>0.120</td>
</tr>
<tr>
<td>- 2nd high-pitch spiral</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>- 2nd low-pitch spiral</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>- 2nd axial</td>
<td>16</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Tube potential ≤100 kV, n (%)</td>
<td>85 (56.7)</td>
<td>76 (49.7)</td>
<td>0.269</td>
</tr>
</tbody>
</table>
Image Quality Score

Comparison between High-pitch first and Conventional first methods. The bar chart shows the Image Quality Score with a p-value of 0.681.

- High-pitch first method: Score 3.81
- Conventional first method: Score 3.83
Prospective ECG-triggered high-pitch coronary CT angiography acquired in a patient (172cm, 67kg, BMI: 22.6 kg/sqm, heart rate: 58bpm). Applying a tube potential of 100 kV, the resulting radiation dose estimate was 0.94 mSv.

Prospective ECG-triggered axial coronary CT angiography acquired in a patient (170cm, 69kg, BMI: 23.9 kg/sqm, heart rate: 64bpm). Applying a tube potential of 100 kV, the resulting radiation dose estimate was 2.6 mSv.
Radiation Dose & Clinical FU

In 49% of high-pitch first patients, the CCTA radiation dose was < 1 mSv.

Total estimated radiation dose

- High-pitch first: 2.0, 4.6
- Conventional first

Follow-up rate: 98.0%

Need for addit. diagnostic studies during 30-day FU

- High-pitch first: 8.1
- Conventional first: 13.5

P < 0.0001

P = 0.129
Iterative Image Reconstruction

Signal intensity: 379 HU
Image noise: 43 HU

Signal intensity: 378 HU
Image noise: 29 HU

Standard filtered back projection

Iterative
PROTECTION V
Prospective Randomized Trial On RadiaTion Dose Estimates Of Cardiac CT AngI0graphy In PatieNts Applying Iterative Image Reconstruction Techniques

400 patients

randomization

200 patients
Reduced tube current + iterative reconstr.

image quality & radiation dose

30-day follow-up

study design: non-inferiority international multi-center multi-vendor

200 patients
Standard tube current + standard reconstr.

image quality & radiation dose

30-day follow-up
SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT

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**KEYWORDS:**
Practice guideline; Radiation dose; Radiation protection; Radiation monitoring; Tomography, x-ray computed; Cardiac-gated imaging techniques; Coronary CT angiography; Coronary calcium scanning; Algorithms

**Abstract.** Over the last few years, computed tomography (CT) has developed into a standard clinical test for a variety of cardiovascular conditions. The emergence of cardiovascular CT during a period of dramatic increase in radiation exposure to the population from medical procedures and heightened concern about the subsequent potential cancer risk has led to intense scrutiny of the radiation burden of this new technique. This has hastened the development and implementation of dose reduction tools and prompted closer monitoring of patient dose. In an effort to aid the cardiovascular CT community in incorporating patient-centered radiation dose optimization and monitoring practice, the Society of Cardiovascular Computed Tomography has \textsuperscript{1} to review available data and provide recommendations regarding interventional and non-invasive predictors of risk, appropriate use of scanner acquisition mode algorithms for dose optimization, and establishment of procedures for dose reduction. The Journal of Cardiovascular Computed Tomography has \textsuperscript{1} to review available data and provide recommendations regarding interventional and non-invasive predictors of risk, appropriate use of scanner acquisition mode algorithms for dose optimization, and establishment of procedures for dose reduction.
Conclusions

- Today, a variety of different, very effective techniques to reduce radiation exposure for coronary CT angiography are available.

- It is at the responsibility of the CT-performing physicians and radiology technicians to reasonably apply these techniques in eligible patients – instead of using a “one scan protocol fits all” approach.

- The available SCCT radiation guidelines may help to perform coronary CT angiographies with the best balance of maintained image quality with the lowest radiation exposure.
Image Quality Score

Score 1: non-diagnostic
Score 2: adequate
Score 3: good
Score 4: excellent
Non-Inferiority Analysis

Margin of non-inferiority vs. conventional-first strategy

better  high-pitch first  worse

high-pitch first strategy

two-sided 95% limit

\( P_{\text{non-inferiority}} < 0.0001 \)

Difference in image quality score

-0.1  0  0.1  0.2
Contour Blurring Score

Vessel contours reflecting the ability of coronary plaque assessment (graininess (mottle) and motion) were analyzed by two experienced CCTA readers on a per-patient basis:

1. **Extensive blurring:** Reliable assessment of vessels contours impossible.

2. **Medium blurring:** Graininess/motion impairing assessment of vessel contours, but still containing sufficient informative value.

3. **Slight blurring:** Minor blurring and/or graininess of the vessel contours.

4. **Minimal or no blurring:** Images with sharp vessel contours and little graininess.
Contour Blurring Score

Score 1: extensive blurring
Score 2: medium blurring
Score 3: slight blurring
Score 4: minimal or no blurring
Contour Blurring Score

P = 0.001

- High-pitch first: 3.3
- Conventional first: 3.6
PROTECTION IV – High-Pitch
Primary study endpoint

Enrollment completed
Currently being analyzed

~ 270 pts
heart rate: 56 ±4 bpm

Estimated radiation dose (mSv)

High pitch first

Conventional first
Radiation Risk

“Potential risk of future stochastic events must be balanced with the potential benefits of the examination and potential risks of forgoing the examination or obtaining a nondiagnostic examination because of excessive dose reduction.”

Image quality comes FIRST!!
Median CCTA Radiation Dose over time @ DHM

(mSv)

04  2005  2006  2007  2008  2009  2010  11
Conclusions

- PROTECTION I described the radiation dose of CCTA and its variability in daily practice.

- The PROTECTION II & III studies demonstrated that image quality is maintained with 100 kVp and axial scan protocols.

- PROTECTION IV evaluates the performance of the high-pitch scan first strategy.
Conclusions

- PROTECTION I described the radiation dose of CCTA and its variability in daily practice.
- The PROTECTION II & III studies demonstrated that image quality is maintained with 100 kVp and axial scan protocols.
- PROTECTION IV evaluates the performance of the high-pitch scan first strategy.
Quantitative Image Quality

- **Signal intensity**: P=0.55, High-pitch first (436) vs. Conventional first (444)
- **Noise**: P=0.04, High-pitch first (26) vs. Conventional first (24)
- **Signal-noise ratio**: P=0.03, High-pitch first (18) vs. Conventional first (19)
- **Contrast-noise ratio**: P=0.02, High-pitch first (14) vs. Conventional first (15)
Estimated Radiation Dose Associated With Cardiac CT Angiography

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Markus Krebs
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Stefan Martinoff, MD
Adnan Kastrati, MD
Albert Schömig, MD
Stephan Achenbach, MD

Context Cardiac computed tomography (CT) angiography (CCTA) has emerged as a useful diagnostic imaging modality in the assessment of coronary artery disease. However, the potential risks due to exposure to ionizing radiation associated with CCTA have raised concerns.

Objectives To estimate the radiation dose of CCTA in routine clinical practice as well as the association of currently available strategies with dose reduction and to identify independent factors contributing to radiation dose.

Design, Setting, and Patients A retrospective study of 190 patients who underwent CCTA at a single center between September 2001 and December 2007. Parameters associated with radiation dose exposure and follow-up were obtained from electronic medical records.

Main Outcome Measures Estimated radiation dose and the potential factors associated with it.

Results The median estimated radiation dose was 9.5 mSv (interquartile range, 5.8 to 16.3 mSv).

Image Quality and Radiation Exposure With a Low Tube Voltage Protocol for Coronary CT Angiography

Results of the PROTECTION II Trial

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Prospective Randomized Trial On Radiation Dose Estimates Of CT Angiography In Patients Scanned With A Sequential Scan Protocol - The PROTECTION III Study


Gewerbliche Praxistum Krankenhaus München, Munich, Germany

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>9.5 mSv</td>
</tr>
<tr>
<td>Interquartile range</td>
<td>5.8 to 16.3 mSv</td>
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</tbody>
</table>
Coronary Stent Images Using the Stellar Detector in Clinical Practice
Coronary Stent Images Using the Stellar Detector in Clinical Practice

Current Flash

Stellar Flash
Stellar Detector - Coronary CTA Sequence
Excellent in-stent restenosis evaluation

Stellar Detector images

Orange arrow: reduced blooming and increased sharpness

SOMATOM Definition Flash
Flash Speed.
Lowest Dose.

HR independent
temp resolution: 75 msec
collimation: 128 x 0.6 mm
spatial resolution: 0.33 mm
scan time: 6 s
scan length: 103 mm
rotation time: 0.28 s
120 kV, 456 mAs / rotation
DLP: 243 mGycm
CTDInvol: 23 mGy

HR: 78 bpm
3.4 mSv

Courtesy of Deutsches Herzzentrum / Munich, Germany
Comparison

Bypass Graft

Footnote: Arial Regular 8 point. line spacing 0.9 line. max. double spaced.

Current Flash

Stellar Flash

Eff. Dose: 1,5 mSv

Eff. Dose: 1,3
Current Flash

Stellar Flash

Eff. Dose: 1,5 mSv

Eff. Dose: 1,3
Stellar Detector in Coronary CTA
Increased vessel delineation and minimized blooming*

Reduced blooming and increased sharpness

Enhancing stent and calcified lesion evaluation

* Under development. Not available for sale in the U.S.
 Courtesy of J. Hausleiter, MD, Cardiologist, German Heart Center, Munich, Germany