Coronary computed tomography angiography with model-based iterative reconstruction using a radiation exposure similar to chest X-ray examination

Tobias A. Fuchs†, Julia Stehli†, Sacha Bull, Svetlana Dougoud, Olivier F. Clerc, Bernhard A. Herzog, Ronny R. Buechel, Oliver Gaemperli, and Philipp A. Kaufmann*

Division of Nuclear Medicine and Cardiac Imaging, University Hospital Zurich, Ramistrasse 100, NUK C 42, CH-8091 Zurich, Switzerland

Received 9 July 2013; revised 3 November 2013; accepted 12 December 2013; online publish-ahead-of-print 19 February 2014

Aims
To evaluate the feasibility and image quality of coronary computed tomography angiography (CCTA) acquisition with a submillisievert fraction of effective radiation dose using model-based iterative reconstruction (MBIR) for noise reduction.

Methods and results
In 42 patients undergoing standard low-dose (100–120 kV; 450–700 mA) and additional ultra-low-dose CCTA (80–100 kV; 150–210 mA) reconstructed with MBIR, segmental image quality was graded on a four-point scale [(i): non-evaluative, (ii): good, (iii): adequate, and (iv): excellent]. Signal-to-noise ratio (SNR) was calculated dividing left main artery (LMA) and right coronary artery (RCA) attenuation by the aortic root noise. Over a wide range of body mass index (18–40 kg/m²), the estimated median radiation dose exposure was 1.19 mSv [interquartile range (IQR): 1.07–1.30 mSv] for standard and 0.21 mSv (IQR: 0.18–0.23 mSv) for ultra-low-dose CCTA (P < 0.001). The median image quality score per segment was 3.5 (IQR: 3.0–4.0) in standard CCTA vs. 3.5 (IQR: 2.5–4.0) in ultra-low dose with MBIR (P = 0.29). Diagnostic image quality (scores 2–4) was found in 98.7 vs. 97.8% coronary segments (P = 0.36). Introduction of MBIR for ultra-low-dose CCTA resulted in a significant increase in SNR (P < 0.001) for LMA (from 15 ± 5 to 29 ± 7) and RCA (from 14 ± 4 to 27 ± 6) despite 82% dose reduction.

Conclusion
Coronary computed tomography angiography acquisition with diagnostic image quality is feasible at an ultra-low radiation dose of 0.21 mSv, e.g. in the range reported for a postero-anterior and lateral chest X-ray.

Keywords
Ultra-low-dose coronary computed tomography angiography • Model-based iterative reconstruction • Feasibility

Introduction
Technical refinements in coronary computed tomography angiography (CCTA) have led to a rapid implementation of CCTA for non-invasive assessment of coronary artery disease (CAD) in daily clinical routine yielding high accuracy compared with invasive coronary angiography.1,2 Recently, CCTA has been found to be most useful in patients with a low-to-intermediate pre-test probability for CAD as the strength of CCTA is based on a high negative predictive value.3 The radiation exposure from CCTA has obtained a growing attention due to its potential risk of cancer induction4 and has stimulated the development of technical refinements for dose reduction. Although the initially reported high radiation dose exposure for CCTA has been substantially reduced from ≏20 to ≏2 mSv or less without loss of image quality or accuracy by introduction of prospective ECG triggering5 including high-pitch spiral,6 any further dose reduction is welcome. Further radiation dose reduction

---

* Corresponding author. Tel: +41 44 255 41 96, Fax: +41 44 255 44 14, Email: pak@usz.ch 
© The Author 2014. Published by Oxford University Press on behalf of the European Society of Cardiology. 
This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com
would require lowering tube voltage and current, which was so far hampered by image quality degradation from progressively increasing noise.

Recently, iterative reconstruction algorithms for image noise reduction such as model-based iterative reconstruction (MBIR; GE Healthcare) have paved the way for lowering tube voltage and current with acceptable image quality in abdominal and chest CT but has not yet been implemented for CCTA.

We tested the hypothesis that ultra-low-dose CCTA achieving image quality comparable with standard CCTA with a submillisievert fraction of effective radiation dose is feasible by introducing the novel reconstruction algorithm MBIR.

**Methods**

**Patients**

We prospectively enrolled 42 consecutive patients who were referred for the assessment of known or suspected CAD with contrast-enhanced CCTA to undergo additional ultra-low-dose contrast-enhanced CCTA if none of the following exclusion criteria were present: hypersensitivity to iodinated contrast agent, renal insufficiency, non-sinus rhythm, and haemodynamic instability.

Patients were referred based on at least one of the following symptoms: dyspnoea (n = 9), typical angina pectoris (n = 10), atypical chest pain (n = 22), pathological exercise test or ECG (n = 17), for follow-up after coronary stenting (n = 1), and due to suspected CAD based on high-risk profile (n = 1). The study was approved by the local ethics committee and written informed consent was obtained from all patients.

**Computed tomography data acquisition and post-processing**

Prior to examination all patients received 2.5 mg isosorbiddinitrate sublingually (Isoket, Schwarz Pharma, Monheim, Germany) and metoprolol (up to 25 mg Beloc, AtraZeneca, London, UK) was administered intravenously if heart beats per minute were >65 b.p.m. in order to obtain optimal image quality for CCTA. Iodixanol (Visipaque 320, 320 mg/mL, GE Healthcare) was injected into an antecubital vein followed by 50 mL saline solution via an 18-cauge catheter. Volume and flow rate were adapted to body surface area (BSA) (50 mL via 4 mL/s: BSA < 1.7 m²; 35 mL via 4 mL/s: BSA 1.7–1.79 m²; 60 mL via 4 mL/s: BSA 1.8–1.94 m²; 80 mL via 4.5 mL/s: BSA 1.95–2.04 m²; 80 mL via 5 mL/s: BSA 2.05–2.14 m²; 85 mL via 5 mL/s: BSA 2.15–2.24 m²; 95 mL via 5 mL/s: BSA 2.25–2.49 m²; 105 mL via 5 mL/s: BSA ≥ 2.5 m²), modified from Pazhenkottil et al.10

All CCTA examinations were performed on a 64 slice CT scanner (Discovery HD 750, GE Healthcare) using prospective ECG triggering during inspiration breath hold as previously reported.7 The scanning parameters were as follows: slice acquisition 64 × 0.625 mm, z-coverage 40 mm with an increment of 35 mm, smallest X-ray window (75% of the RR-cycle), gantry rotation time 350 ms, and body mass index (BMI) adapted tube voltage and tube current for ultra-low-dose and standard CCTA (Table 1).

Standard CCTA was reconstructed using a blending factor of 30% of adaptive statistical iterative reconstruction (ASIR; GE Healthcare) according to clinical standards established in our institution.11 In brief, ASIR reconstructs pictures by comparing measured projection with a synthesised projection using both statistical fluctuation calculations and system optics.12 Ultra-low-dose CT was reconstructed using MBIR (GE Healthcare), an iterative reconstruction algorithm on the basis of multiple statistical models incorporating optical system geometry and system statistics (e.g. image noise).13 As MBIR is not yet commercially available for CCTA reconstructions, datasets were transferred outside our department on an external workstation and reconstructed by the vendor (GE Healthcare). The effective radiation dose from CCTA was calculated as the product of dose-length product (DLP) times a conversion coefficient for chest [k = 0.014 mSv/(mGy cm)].2,14

**Computed tomography image analysis**

Coronary arteries were segmented as suggested by the American Heart Association.15 All segments with a diameter of at least 1.5 mm at their origin were included. Two readers semi-quantitatively assessed independently the overall image quality on a four-point Likert scale (i): non-evalulative, severe artefacts; (ii): adequate, moderate artefacts; (iii): good, minor artefacts; and (iv): excellent, no artefacts) adapted as previously reported.1 To measure attenuation in the left main artery (LMA) and in the proximal right coronary artery (RCA), regions of interest (ROIs) were drawn as large as possible, carefully avoiding calcifications, plaques, and stenoses. Noise was defined as the standard deviation of the attenuation in a circular ROI placed into the aortic root. Signal-to-noise ratio (SNR) was calculated for LMA and RCA by dividing the attenuation in the respective coronary vessel by the noise.

**Statistical analysis**

SPSS 20.0 (SPSS, Chicago, IL, USA) was used for all statistical analysis. Quantitative data were expressed as mean ± SD or median and interquartile range (IQR), when appropriate. The Wilcoxon signed-rank test and with normal distribution with Student’s paired t-test. Contingency analysis was performed using Fisher’s exact test. We took into account the repeated structure of the measures and the hierarchical data structure (i.e. the fact that the segments and vessels were clusters of observations in the patients). To this aim, a multilevel analysis was performed on three levels (patient as the first level, vessels being the second level, and segments the third). Therefore generalised linear mixed modelling was used. Because of the skewness of the target variable gamma distribution was applied with identity link function.16,17 P-values of <0.05 (two tailed) were considered statistically significant.
Results

Ultra-low-dose and standard CCTA was successfully performed in all 42 patients (14 women, 28 men; mean age 55 ± 10 years; age range 34–71 years) presenting with the following cardiovascular risk factors: 21 were smokers (50%), 1 had diabetes (2%), 13 had arterial hypertension (31%), 16 had dyslipidaemia (38%), and 13 had a positive family history of CAD (31%) (Table 2).

Coronary computed tomography angiography revealed unknown CAD in six patients. In one patient with known CAD, CCTA revealed an open bioabsorbable stent. The mean BMI of the study population was 25.2 ± 3.8 kg/m² (range: 18.4–40.2 kg/m²) with a mean weight of 74.6 ± 13.1 kg (range: 46.5–112.0 kg). After i.v. beta-blocker administration for heart rate control prior to CCTA in 33 patients (79%) (14.5 ± 8.2 mg, range: 3–25 mg), the mean heart rate was 56.7 ± 5.7 b.p.m. during ultra-low-dose CCTA and 56.9 ± 5.7 b.p.m. during standard CCTA (P = 0.95).

The median DLP from ultra-low-dose vs. standard CCTA was 14.9 mGy cm (IQR: 13.2–16.2 mGy cm) vs. 84.7 mGy cm (IQR: 76.2–93.2 mGy cm) (P < 0.0001) resulting in an estimated median radiation dose of 0.21 mSv (IQR: 0.18–0.23 mSv) vs. 1.19 mSv (IQR: 1.07–1.30 mSv) (P < 0.0001; Figure 1). This represents an 82% dose reduction (P < 0.0001).

The calcium score in the study population ranged from 0 to 2189 (median 141). In the 20 patients with coronary calcifications (calcium score above 0), the calcium score averaged 335 ± 499.

In 42 patients, a total of 168 vessels and 551 coronary artery segments with a diameter of ≥1.5 mm were evaluated (of theoretically 672 segments in 42 patients with 16 coronary segments, 121 were missing because of anatomical variants or diameter <1.5 mm at their origin). Inter-observer agreement of image quality rating was good (κ = 0.68; Figure 2).

Both CCTA protocols yielded good to excellent image quality per segment, per coronary, and per patient (Table 3). The multilevel analysis showed no significant differences in the image quality between ultra-low-dose and standard CCTA (n = 1104 (third level), P = 0.525).

In ultra-low-dose and standard CCTA 97.8% and 98.7% of coronary segments were of diagnostic image quality (score >1) (Figure 3).

Mean image noise decreased significantly from 32 ± 8 Hounsfield units (HU) in standard CCTA to 20 ± 3 HU in ultra-low-dose CCTA (P < 0.001). Interestingly, this was accompanied by an increase in mean attenuation in LMA from 456 ± 82 to 558 ± 121 HU and in RCA from 444 ± 72 to 511 ± 100 HU (P < 0.001). Thus, the introduction of ultra-low-dose CCTA with MBIR resulted in a significant increase in SNR (P < 0.001) for LMA (from 15 ± 5 to 29 ± 7) and RCA (from 14 ± 4 to 27 ± 6, Table 4).

Discussion

This study is the first to demonstrate the feasibility of ultra-low-dose CCTA with MBIR for noise reduction in a broad spectrum of patients as seen in daily clinical routine over a wide range of BMI. Despite a substantial radiation dose reduction, median image quality was not significantly different to standard CCTA and 97.8% of coronary segments were interpretable yielding comparable or even higher image quality scores than reported in other CCTA studies.

Table 2  Patient baseline characteristics

| Number of patients (n) | 42 |
|------------------------|----|
| Age (years)            | 55 ± 10 (34–71) |
| Male/female            | 28/14 |
| BMI (kg/m²)            | 25.2 ± 3.8 (18.4–40.2) |
| Drug administration, n (%) | |
| Beta-blocker           | 33 (79) |
| Nytroglycerin          | 42 (100) |
| Heart rate (b.p.m)     | |
| Standard CCTA          | 56.9 ± 5.7 (49–70) |
| Ultra-low-dose CCTA    | 56.7 ± 5.7 (49–75) |
| Clinical symptoms, n (%) | |
| Dyspnoea               | 9 (21) |
| Typical AP             | 10 (24) |
| Atypical chest pain    | 22 (52) |
| None                   | 10 (24) |
| Cardiovascular risk factors, n (%) | |
| Smoking                | 21 (50) |
| Diabetes               | 1 (2) |
| Arterial hypertension  | 13 (31) |
| Dyslipidaemia          | 16 (38) |
| Positive family history| 13 (31) |

Values are given as mean ± SD and ranges (in brackets) or absolute numbers and percentages (in brackets).

BMI, body mass index; CCTA, coronary computed tomography angiography; AP, angina pectoris.

Figure 1  Effective estimated radiation dose for each patient from ultra-low-dose (●) and standard coronary computed tomography angiography (○).
The comparable image quality of ultra-low-dose vs. standard CCTA was enabled by an effective noise reduction by MBIR resulting in an even lower image noise in ultra-low-dose compared with standard CCTA. In combination with the shift towards higher beam attenuation by iodine in low tube voltage scanning, this resulted in an SNR substantially higher than in standard CCTA. Despite increasing noise due to less photon emission at such low tube current and peak voltage, this containment of radiation dose was enabled by one of the latest iterative reconstructions algorithms such as MBIR, which incorporates modelling of the photon and noise statistics, but also involves modelling of system optics.18 Recently, CCTA with reasonable image quality and a radiation dose as low as 0.06 mSv has been achieved in a study population with <100 kg using a similar modern iterative reconstruction algorithm from another vendor (SAFIRE, Siemens Healthcare, Forcheim, Germany).19 However, their reported SNR for the coronary arteries averaged 5, whereas in our study this value averaged 27–29.

It is relevant to point out that the median effective radiation dose of 0.21 mSv achieved with the present protocol is even substantially lower than, for example, the effective radiation dose for standard coronary calcium score scanning.20 Coronary computed tomography angiography at such low exposure opens new doors for non-invasive assessment. This is particularly remarkable as our protocol resulted in a median exposure of 0.21 mSv, close to the dose of a postero-anterior and lateral chest X-ray, which is reported to range from 0.05 to 0.24 mSv in the literature.21–23

It is generally accepted that the strength of CCTA lies in its high negative predictive value for CAD. Consequently, the consensus is to consider the use of CCTA mainly in low-to-intermediate probability populations24 due to its excellent ability to rule out CAD. As such populations, however, are inherently characterised by a low risk for cardiac events it is unlikely that any diagnostic or therapeutic procedure will further improve the outcome.25 This put the bars very high for any technique to keep a positive balance of harms and benefits for any diagnostic tool, evoking a vivid discussion on the potential carcinogenic risk of CCTA and its justification for a purely diagnostic test. As a consequence, this has fuelled an intense search for strategies to minimise radiation exposure while maintaining image quality. In the past years radiation dose reduction has been successfully achieved by introducing scanning protocols with prospective ECG triggering, limiting the beam to a narrow diastolic phase.5 The new protocol represents yet another milestone for further substantial dose reduction from CCTA as new reconstruction algorithms for noise reduction allow decreasing tube current and voltage. This further shifts the tip of the benefit-to-harm balance favourably towards clinical benefits, where potentially even screening and monitoring of CAD therapy effects may no longer appear prohibitive for radiation safety concerns. It appears foreseeable that the presented development of latest iterative reconstruction algorithms will soon enter the clinical arena for CCTA and its implementation on different scanners from multiple vendors will allow a widespread use offering substantial decrease in radiation from CCTA to a large patient population in the near future.

It may be perceived as a potential limitation of this study that diagnostic accuracy and stenosis measurement was not compared with invasive coronary angiography. However, the high accuracy of standard CCTA has been previously established and, therefore, it seems reasonable to use it as a ground of truth reference standard. Another limitation is that the MBIR algorithm is currently not yet approved for clinical use in CCTA, whereas it is commercially

### Table 3 Image quality

|                  | Ultra-low-dose CCTA | Standard CCTA | P-value |
|------------------|---------------------|---------------|---------|
| Per segment      | 3.5 (2.5–4.0)       | 3.5 (3.0–4.0) | 0.29    |
| (n = 551)        |                     |               |         |
| Per artery       | 3.5 (3.1–4.0)       | 3.5 (3.0–4.0) | 0.84    |
| (n = 168)        |                     |               |         |
| Per patient      | 3.4 (2.9–3.6)       | 3.3 (3.1–3.6) | 0.60    |
| (n = 42)         |                     |               |         |

Values of image quality are given as median and IQR (in brackets). P-values are reported from Wilcoxon signed-rank test.

CCTA, coronary computed tomography angiography.
available for non-cardiac use since several years. Furthermore, prevalence of coronary calcifications in the present study population was moderate. It cannot be excluded that in patients with higher prevalence of massive coronary calcifications image quality may be impaired, particularly in ultra-low-dose CCTA. However, we are in line with the general recommendations to use CCTA preferentially in patients with low CAD risk profile and, thus, lower prevalence of coronary calcifications. Finally, larger studies may be helpful to establish how the promising results of the present study can be implemented into daily routine.

In conclusion, CCTA acquisition with diagnostic image quality is feasible at an ultra-low radiation dose of 0.21 mSv, e.g. in the range reported for a postero-anterior and lateral chest X-ray.

Acknowledgements

The study was supported by a grant from the Swiss National Science Foundation to P.A.K. Furthermore, we thank our radiographers Ennio Mueller, Gentian Cermjani, and Franziska Jann for their excellent technical support. We are grateful to Jean-Baptiste Thibault, (GE, Healthcare) for MBIR reconstruction.

Funding

Funding to pay the Open Access publication charges for this article was provided by Institutional Research Funds.

Conflict of interest: Institutional research contract with GE Healthcare.
References

1. Herzog BA, Husmann L, Burkhard N, Gaemperli O, Valenta I, Tatsugami F, Wyss CA, Landmesser U, Kaufmann PA. Accuracy of low-dose computed tomography coronary angiography using prospective electrocardiogram triggering: first clinical experience. Eur Heart J 2008;29:3073–3042.

2. Buechel RR, Husmann L, Herzog BA, Pazhenkottai AP, Nikouluor R, Ghadri JR, Treyer V, von Schulthess P, Kaufmann PA. Low-dose computed tomography coronary angiography with prospective electrocardiogram triggering: feasibility in a large population. J Am Coll Cardiol 2011;57:332–336.

3. Schroeder S, Achenbach S, Bengel F, Burghammer C, Cademartiri F, de Feyter P, George R, Kaufmann P, Kopp AF, Knust J, Ropers D, Schepis T, Achenbach S, Marwan M, Ropers D, Schepis T, Pflederer T, Anders K, Kuettner A, Knuuti J. Ionizing radiation risks of cardiac imaging: estimates of the immeasurable. Eur Heart J 2011;32:269–271.

5. Husmann L, Valenta I, Gaemperli O, Adda O, Treyer V, Wyss CA, Veit-Haibach P, Tatsugami F, von Schulthess GK, Kaufmann PA. Feasibility of low-dose coronary CT angiography: first experience with prospective ECG-gating. Eur Heart J 2008;29:191–197.

6. Achenbach S, Marwan M, Ropers D, Schepis T, Pflederer T, Anders K, Kruettner A, Daniel WG, Uder M, Lell MM. Coronary computed tomography angiography with a consistent dose below 1 mSv using prospectively electrocardiogram-triggered high-pitch spiral acquisition. Eur Heart J 2010;31:340–346.

7. Thibault JB, Sauder KD, Bouman CA, Hsieh J. A three-dimensional statistical approach to improved image quality for multislice helical CT. Med Phys 2007;34:4526–4544.

8. Pickhardt PJ, Lubner MG, Kim DH, Tang J, Ruma JA, del Rio AM, Chen GH. Abdominal CT with model-based iterative reconstruction (MBIR): initial results of a prospective trial comparing ultralow-dose with standard-dose imaging. Am J Roentgenol 2012;199:1266–1274.

9. Katsura M, Matsuda I, Akahane M, Satoh J, Akai H, Yasaka K, Kunimoto A, Ohtomo K. Model-based iterative reconstruction technique for radiation dose reduction in chest CT: comparison with the adaptive statistical iterative reconstruction technique. Eur Radiol 2012;22:1613–1623.

10. Pazhenkottai AP, Husmann L, Buechel RR, Herzog BA, Nikouluor R, Burger IA, Vetterli A, Valenta I, Ghadri JR, von Schulthess P, Kaufmann PA. Validation of a new contrast material protocol adapted to body surface area for optimized low-dose CT coronary angiography with prospective ECG-gating. Int J Cardiovasc Imaging 2010;26:591–597.

11. Pazhenkottai AP, Husmann L, Valenta I, Ghadri JR, von Schulthess P, Kaufmann PA. Image quality in low-dose coronary computed tomography angiography with a new high-definition CT scanner. Int J Cardiovasc Imaging 2013;29:471–477.

12. Leipsic J, Labounty TM, Hellbrun B, Min JK, Mancini GB, Lin FY, Taylor C, Dunning A, Earls JP. Adaptive statistical iterative reconstruction: assessment of image noise and image quality in coronary CT angiography. Am J Roentgenol 2010;195:649–654.

13. Fuchs TA, Fiechter M, Gebhard C, Stehli J, Ghadri JR, Kazakauskaite E, Herzog BA, Husmann L, Gaemperli O, Kaufmann PA. CT coronary angiography: impact of added statistical iterative reconstruction (ASIR) on coronary stenosis and plaque composition analysis. Int J Cardiovasc Imaging 2013;29:719–724.

14. Hausleiter J, Meyer T, Hermann F, Hadamitzky M, Krebs M, Gerber TC, McColloagh C, Martinoff S, Kastrati A, Schomig A, Achenbach S. Estimated radiation dose associated with cardiac CT angiography. JAMA 2009;301:500–507.

15. Asten WG, Edwards JE, Frye RL, Gennis GG, Gitt VL, Griffith LS, McGoogan DC, Murphy ML, Roe BB. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. Circulation 1979;51:5–40.

16. Heek RH, Thomas SL. Multilevel Modeling of Categorical Outcomes Using IBM SPSS. New York, NY 10017: Taylor and Francis Group, 2003.

17. Singer JD, Willett JB. Applied Longitudinal Data Analysis/Modeling Change and Event Occurrence. New York: Oxford University Press, 2003.

18. Schellff H, Stolzmann P, Schlett CL, Engel LC, Major GP, Karolym D, Sa Mauro-Horvat P, Hoffmann U. Coronary artery plaques: cardiac CT with model-based and adaptive-statistical iterative reconstruction technique. Eur J Radiol 2012;81:e363–e369.

19. Schultze-Beaev A, Achenbach S, Layritz C, Essentopf J, Hecker F, Pflederer T, Gauss S, Rixe, J, Kaulenberg W, Daniel WG, Leil M, Ropers D. Image quality of ultra-low radiation exposure coronary CT angiography with an effective dose &lt;0.1 mSv using high-pitch spiral acquisition and raw data-based iterative reconstruction. Eur Radiol 2013;23:597–606.

20. Ghadri JR, Goetti R, Fiechter M, Pazhenkottai AP, Kuest SM, Nikouluor RN, Windler C, Buechel RR, Herzog BA, Gaemperli O, Templin C, Kaufmann PA. Inter-scan variability of coronary artery calcium scoring assessed on 64-multidetector computed tomography vs. dual-source computed tomography: a head-to-head comparison. Eur Heart J 2011;32:1865–1874.

21. European Society of Radiology: Radiography of the Lung. http://patientinfo.myesr.org/html_frontend/index.php?module=article&action=&article_id=166 (30 October 2013).

22. Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. Radiology 2008;248:254–263.

23. Nerioladaki A, Botsikas D, Boudabous S, Becker CD, Montet X. Computed tomography of the chest with model-based iterative reconstruction using a radiation exposure similar to chest X-ray examination: preliminary observations. Eur Radiol 2013;23:360–366.

24. Perrone-Filardi P, Achenbach S, Mohlenkamp S, Reiner Z, Sambucetti G, Schuijf JD, van der Wall E, Kaufmann PA, Knusti J, Schroeder S, Zellweger MJ. Cardiac computed tomography and myocardial perfusion scintigraphy for risk stratification in asymptomatic individuals without known cardiovascular disease: a position statement of the Working Group on Nuclear Cardiology and Cardiac CT of the European Society of Cardiology. Eur Heart J 2011;32:1986–1993, 1993a, 1993b.

25. Kaufmann PA. Low-dose computed tomography coronary angiography with prospective triggering: a promise for the future. J Am Coll Cardiol 2008;52:1456–1457.