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Low-dose, 128-slice, dual-source CT coronary angiography: accuracy and radiation dose of the high-pitch and the step-and-shoot mode

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ABSTRACT

Objective To compare the diagnostic accuracy and radiation doses of two low-dose protocols for coronary artery imaging with second-generation, dual-source CT in comparison with catheter angiography (CA).

Design, setting and patients Prospective, singlecentre study conducted in a referral centre enrolling 100 patients with low-to-intermediate risk and suspicion of coronary artery disease. All patients underwent contrastenhanced, 128-slice, dual-source CT coronary angiography and CA. Patients were randomly assigned to two different low-dose CT protocols (each 100 kV/ 320 mA): in group A (n=50), CT was performed using the prospectively electrocardiography (ECG)-gated stepand-shoot (SAS) mode; in group B (n=50), CT was performed using the prospectively ECG-gated high-pitch mode (pitch 3.4). The image guality and presence or absence of significant coronary stenosis in all coronary segments were evaluated by two blinded and independent observers. CA served as the standard of reference. Results Sixty-one significant stenoses were found in group A, and 69 in group B. There was no significant difference in age (group A, 62±8yrs; group B, 63±8yrs; p=0.72), body mass index (group A, 26.4 \pm 3.1kg/m2: group B, 25.9 ± 2.8 kg/m2; p=0.41) and heart rate (HR) (group A. 58±8bpm; group B. 56±10bpm; p=0.66) between the groups. Diagnostic image quality was obtained in 98.6% (651/660) of segments in group A and in 98.9% (642/649) in group B, with no significant differences between groups. Sensitivity, specificity and positive and negative predictive values were 94%, 91%, 85% and 97% per-patient in group A, and 93%, 94%, 89% and 97% per-patient in group B (no significant differences). The effective radiation dose in group B $(0.9\pm0.1 \text{ mSv})$ was significantly (p<0.01) lower than that in group A $(1.4\pm0.4 \text{ mSv})$.

Conclusions Both the high-pitch and the SAS mode for low-dose CT coronary angiography provide high accuracy for the assessment of significant coronary stenoses, while the high-pitch mode further significantly lowers the radiation dose.

INTRODUCTION

Cardiac CT is a reliable and accurate modality for the diagnosis or exclusion of coronary artery disease (CAD). A large number of studies have investigated the diagnostic performance of CT coronary angiography among different generations of CT scanners.¹ Although the high image quality and diagnostic accuracy are generally acknowledged, radiation doses

associated with the non-invasive modality have been a matter of continuous concern.² In a recent multicentre, multivendor trial, Hausleiter *et al*³ could show a median effective radiation dose of 12 mSv for CT coronary angiography with retrospective electrocardiography (ECG) gating, while some sites used protocols exceeding even 30 mSv. The problem of radiation associated with cardiac CT is mainly the result of the low pitch values, typically ranging between 0.2 and 0.5, which are required for acquisition of data in the spiral mode.^{2–4}

Various strategies to reduce radiation exposure of patients have been developed, the most important one being prospectively ECG-gated CT coronary angiography, also called step-and-shoot (SAS) mode. The SAS mode is characterised by turning on the x-ray tube only at a predefined time point of the cardiac cycle, usually in mid-diastole, while keeping the patient table stationary. The x-ray exposure time of this technique is short, and thus, low radiation doses ranging between 1.2 and 4.3 mSv have been reported using various 64-slice and first-generation, dual-source 64-slice CT.^{5–7} Most importantly, this low-dose SAS method was still accurate.⁷

With the recent advent of second-generation, dualsource CT equipped with two 128-slice acquisition detectors, another low-dose technique-that is, high-pitch mode, has been introduced for cardiac CT.9 In this mode, data acquisition is also prospectively triggered with the ECG of the patient. However, the data are acquired in a spiral mode while the table runs with a very high pitch of 3.4, equalling a table feed of 46 cm/s. When this high-pitch mode is used, the entire heart can be scanned within one single cardiac cycle, usually during diastole. The temporal resolution of this system, owing to the gantry rotation time of 280 ms and using a quarter rotation for data reconstruction, is 75 ms for all cardiac scanning modes. Early reports on phantoms and animals⁹ have shown the ability of this scan mode to deliver images of diagnostic quality at a low radiation dose. Moreover, two proof-of-concept studies using the high-pitch mode on remodelled firstgeneration, dual-source 64-slice CT scanners indicated the feasibility of this technique also in human coronary arteries,¹⁰ ¹¹ with similar results in several feasibility studies^{12–15} and a first accuracy study¹⁶ using second-generation, dual-source CT. However, to date no study has evaluated and compared the accuracy and radiation doses of both the SAS and the high-pitch mode with dual-source 128-slice CT.

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CT coronary angiography

Thus, our study had three purposes: (*a*) to prospectively assess the diagnostic performance of 128-slice, dual-source CT coronary angiography for the diagnosis of significant coronary stenoses in the SAS mode; (*b*) to prospectively assess the diagnostic performance of 128-slice, dual-source CT coronary angiography in the high-pitch mode, and (*c*) to compare the accuracy and radiation doses of both low-dose protocols.

MATERIALS AND METHODS Patient population

Between May and August 2009, a total of 100 consecutive patients were enrolled in this study (figure 1). There was no overlap in patient inclusion with our previous, first experience study.¹⁶ All underwent cardiac CT using a second-generation, 128-slice, dual-source CT scanner (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany).

All patients had atypical chest pain, an inconclusive exercise ECG or were unable to exercise, and all had a low-to-intermediate risk of cardiovascular disease (according to Diamond and Forrester¹⁷). The normalcy rate, defined as the percentage of patients who have a <5% pretest likelihood of CAD and who have a normal test, was 0%. Patients with nephropathy, known hypersensitivity to iodine-containing contrast media, non-sinus rhythm, previous aortocoronary bypass grafts, previous



Figure 1 Flow chart demonstrating study design and patient enrolment. CABG, coronary artery bypass graft; CAD, coronary artery disease.

myocardial infarction and previous coronary stent implantation were excluded. In both groups, patients with heart rates >70 bpm were excluded from the study. Heart rates above this level are considered a contraindication for dual-source CT coronary angiography in the SAS mode.⁸ To maintain similar inclusion criteria for both groups and to facilitate the randomisation process, we used the same upper boundary heart rate (ie, 70 bpm) also for the high-pitch mode group.

Each group of 50 patients were randomly assigned in a 1:1 fashion to one of the two low-dose protocols, choosing a block randomisation approach with block sizes of 10. Thus, 50 patients (12 women, 38 men; mean age, 62 years \pm 8 (SD)) were examined using a SAS protocol, and 50 patients (14 women, 36 men; mean age, 63 years \pm 8) were examined in the high-pitch mode.

Each patient underwent catheter angiography (CA) within 2 weeks of CT coronary angiography (median time interval, 8 days).

This prospective study was approved by the local ethics committee; all patients gave written informed consent.

CT scan protocols and data reconstruction

All patients received a single dose of 2.5 mg isosorbide dinitrate s l. (Isoket, Schwarz Pharma, Monheim, Germany). Then, 60-80 ml of iopromide (Ultravist 30, 370 mg/ml, Bayer Schering Pharma, Berlin, Germany) was injected at a flow rate of 6 ml/s followed by 60 ml of saline solution. Contrast agent application was controlled by bolus tracking in the ascending aorta (signal attenuation threshold 100 HU). Data acquisition was initiated with a delay of 8 s after reaching the threshold.

CT parameters for both protocols were as follows: detector collimation $2\times64\times0.6$ mm, slice acquisition $2\times128\times0.6$ mm by means of a z-flying focal spot, gantry rotation time 280 ms, tube current time product 320 mA per rotation and tube voltage 100 kV. CT was performed from 2 cm below the level of the tracheal bifurcation to the diaphragm in a craniocaudal direction.

For the SAS mode, the data acquisition was triggered with the ECG in a prospective fashion. A minimum cycle time of 1.36 s for one acquisition and the subsequent table feed is required. The temporal resolution was 75 ms. The centre of data acquisition window was set at 70% of the R–R interval.

For the high-pitch mode, the start phase for data acquisition of the most cranial slice was selected at 60% of the R–R interval in all 50 patients. The pitch was set to the maximum of 3.4, as previously recommended.¹⁰ ¹¹ ¹⁴

Images for both protocols were reconstructed with a slice thickness of 0.6 mm, a reconstruction increment of 0.4 mm and using a soft-tissue convolution kernel (B26f). For vessel wall calcifications, additional images were reconstructed using a sharp-tissue convolution kernel (B46) to compensate for blooming artefacts.

CT image evaluation

All images were evaluated by two independent readers (with 5 and 7 years experience in cardiovascular imaging, respectively), who were blinded to the clinical information and results from CA. Data were evaluated using axial source images and multiplanar reformations on a per-segment basis. Disagreements in data analysis between the two observers were resolved by consensus reading.

All coronary artery segments with a diameter of $\geq 1 \text{ mm}$ at their origin (as measured by electronic callipers) were identified

Figure 2 Prospectively ECG-gated 128-slice, dual-source CT coronary angiography in the step-and-shoot mode (effective radiation dose 1.5 mSv) in a 56-year-old man with atypical chest pain and inconclusive exercise treadmill test, 4 years after aortic valve surgery. The average heart rate during CT was 59 bpm, the body weight of the patient was 81.3 kg, and the body mass index was 26.3 kg/m². Curved multiplanar reformation of the right coronary artery (RCA) (a) shows slight calcifications in the distal segment, but no stenoses. Catheter angiography of the RCA confirmed the absence of a coronary stenosis (b).



following the 16-segment classification model of the American Heart Association. $^{18}\,$

Image quality of all coronary artery segments was classified as diagnostic or non-diagnostic. The reasons for non-diagnostic image quality were noted.

All diagnostic coronary artery segments were assessed for the presence of significant stenoses, defined as a luminal diameter narrowing of >50%. The vessel diameters were measured on reconstructions perpendicularly oriented to the vessel course. Each vessel was analysed on at least two imaging planes, one parallel and one perpendicular to the course of the vessel.

Radiation dose estimates of CT coronary angiography

For estimation of the radiation doses, the scan length, CT volume–dose index and dose–length product were recorded. The effective radiation dose from CT coronary angiography was derived by multiplying the dose–length product by a conversion coefficient (k). The conversion coefficient (k=0.017 mSv/(mGy×cm)) was averaged between female and male models using Monte Carlo simulations.

Quantitative coronary angiography

One reader (with 4 years' experience of analysing catheter angiograms), who was blinded to the clinical information and the results from CT coronary angiography, examined each catheter angiogram by computerised quantitative coronary angiography (QCA) analysis software (Xcelera; Philips Medical Systems, Best, The Netherlands). Coronary artery segments were identified according to the same classification model mentioned above.¹⁸ CA was performed in at least two orthogonal projections. Coronary artery stenoses were searched for and defined as significant if the mean luminal diameter narrowing exceeded 50%.

Statistical analysis

The sample size was determined given a segment-based analysis of accuracy. Assuming that there were 14 segments per patient and a variance inflation factor of 1.3, a z test with a two-sided significance level of p=0.05 will have 97% power to detect the difference between proportions of 90% and 95% when there are 50 patients in each group.

Heart rate variability was defined as SD from the average heart rate

 κ Statistics were calculated for interobserver agreements for image quality readout and assessment of significant coronary artery stenosis with CT coronary angiography.

Because patients with non-assessable coronary artery segments would undergo CA in clinical practice, we considered non-assessable segments at seen CT as false-positive findings for further statistical analysis. Severity of CAD was defined as the number of coronary arteries with significant stenoses.

Continuous variables were expressed as the mean±SD and range; and categorical variables as frequencies or percentages.

Figure 3 Prospectively ECG-gated 128-slice dual-source CT coronary angiography in the high-pitch mode (effective radiation dose 0.8 mSv) in a 59-year-old man with atypical chest pain and inconclusive exercise treadmill test. The average heart rate during CT was 58 bpm, the body weight of the patient was 79.5 kg, and the body mass index was 26.0 kg/m². Curved multiplanar reformation of the left anterior descending coronary artery (a) shows a significant stenosis in the midsegment (arrow) caused by a noncalcified plaque that was confirmed with catheter angiography (b).



CT coronary angiography

Nominal variables were compared between the two groups by χ^2 and Fisher exact tests, if appropriate. The non-parametric Mann–Whitney U test with exact p values was used to compare ordinal and continuous variables.

Diagnostic accuracy, sensitivity, specificity and positive and negative predictive values of CT coronary angiography for the detection of significant coronary stenoses were calculated with the corresponding 95% CIs on a per-segment basis (presence of at least one, or absence of any, significant stenosis in one coronary artery segment), on a per-vessel basis (presence of at least one, or absence of any, significant stenosis in one coronary artery) and on a per-patient basis (presence of at least one, or absence of any, significant stenosis per patient). QCA was considered as the reference standard.

Statistical analysis was performed using commercially available software (SPSS, release 15.0 for Windows, Chicago, Illinois, USA). A p value < 0.05 was considered to indicate statistical significance.

RESULTS

Patient demographics

Comparisons of demographic data for the patient groups are listed in table 1. No significant difference was found for all demographic parameters among the two groups. The average heart rate in the SAS group was 58 ± 8 bpm and in the high-pitch group 56 ± 10 bpm, with no significant difference between groups (p=0.66).

CT image quality

A total of 660 segments in the SAS group and 649 segments in the high-pitch group were evaluated. Interobserver agreement for image quality ratings between readers was excellent ($\kappa = 0.88$).

Domographico	Step-and-shoot	High-pitch	n Valua
Demographics	mode (n=50)	mode (n = 50)	p value
Age (years)	62±8	63±8	0.72
Sex (female/male)	12/38	14/36	0.65
Body weight (kg)	82.2±6.8	80.7±7.0	0.33
Range	61.2-92.3	55.7-91.5	
BMI (kg/m ²)	26.4±3.1	25.9±2.8	0.41
Range	22.3—30.8	23.5-31.2	
Cardiovascular risk factors			
Diabetes	26% (13/50)	20% (10/50)	0.48
Elevated serum cholesterol (≥5mmol/l)	34% (17/50)	38% (19/50)	0.68
Hypertension (systolic blood pressure \geq 140 mm Hg)	46% (23/50)	46% (23/50)	1.00
Obesity (≥27 kg/m ²)	8% (4/50)	14% (7/50)	0.34
Smoking	42% (21/50)	36% (18/50)	0.54
Positive family history	18% (9/50)	16% (8/50)	0.79
Scanning parameters			
Application of β blockers	30% (15/50)	34% (17/50)	0.67
Average heart rate (bpm)	58±8	56±10	0.66
range	50-69	49-68	
Heart rate variability*	1.0±0.5	1.1±0.8	0.81
Scan range (mm)	117±17	120±10	0.89
Scan duration (s)	5.01±0.94	0.25 ± 0.01	< 0.001
Radiation dose parameters			
CT volume dose index (mGy)	6.9±1.4	4.2±0.9	<0.01
DLP (mGy \times cm)	81±16	50±7	<0.01
Effective dose (mSv)	1.4±0.4	0.9±0.1	<0.01

*Defined as SD of the average heart rate.

DLP, dose-length product.

Diagnostic image quality was found in 98.6% (651/660) of all segments among the SAS group and in 98.9% (642/649) of all segments among the high-pitch group. There was no significant difference between the rate of segments depicted with diagnostic image quality in the two groups (p=0.97).

In the SAS group, non-diagnostic image quality was caused by misalignment (n=3), motion artefacts (n=2), by blooming caused by vessel wall calcification (n=2) and by image noise (n=2). In the high-pitch group, non-diagnostic image quality was caused by motion artefacts (n=4), vessel wall calcification (n=2) and by image noise (n=1).

In the SAS group, the nine coronary segments 2 (n=2), 3 (n=2), 4 (n=1), 9 (n=2), 10 and 14 were of non-diagnostic image quality. In the high-pitch group, the seven coronary segments 2, 3 (n=2), 13, 14 (n=2) and 10 were of non-diagnostic image quality.

Thus, non-diagnostic image quality was most often present in distal coronary segments and side branches in both modes, while middle coronary artery segments showed less non-diagnostic image quality. Non-diagnostic image quality did not occur in proximal segments with both scan modes.

Prevalence of coronary artery disease

With QCA as the standard of reference, 9.2% (61/660) of significant stenosis per segment was found in the SAS group and 10.6% (69/649) of significant stenoses per segment in the high-pitch group (p=0.42).

According to QCA, single-vessel disease was present in the SAS group in 20% (10/50), two-vessel disease in 10% (5/50) and three-vessel disease in 6% (3/0) of patients. In the high-pitch group, single-vessel disease was present in 22% (11/50), (figure 3) two-vessel disease in 6% (3/50) and three-vessel disease in 6% (350) of patients. Significant coronary stenoses could be excluded in 64% (32/50) of patients in the SAS group and in 66% (33/50) in the high-pitch group.

Non-obstructive CAD was found in 85 of the 660 segments (12.9%) in the SAS group (figure 2), and in 98 of the 649 segments (15.1%) in the high-pitch group (p=0.13).

Diagnostic performance

The κ value for coronary artery stenosis detection with CT coronary angiography (including both protocols) was 0.77, indicating good interobserver agreement between readers. The segment-based, vessel-based and patient-based accuracy, sensitivity, specificity, and positive and negative predictive values are listed in table 2. All parameters characterising diagnostic performance showed no significant differences between the two low-dose scan modes.

Radiation doses of low-dose CT coronary angiography

Significant differences were found between the SAS and the high-pitch mode for the effective dose (p<0.01), CT volume dose index (p<0.01), and dose–length product (p<0.01), while the scan range was not significantly different between the two groups (p=0.89) (see table 1).

DISCUSSION

Our study demonstrates that both low-dose protocols of 128slice, dual-source CT share a high diagnostic performance at low radiation doses. The high-pitch mode, when compared with the SAS mode, further lowers the radiation dose to levels <1 mSv.

Radiation dose of low-dose cardiac CT

Radiation dose in cardiac CT is closely related to the pitch value. The pitch values for spiral coronary CT angiography are

 Table 2
 Comparison of the two low-dose protocols for CT coronary angiography for diagnosing significant coronary stenoses

	Step-and-shoot mode			High-pitch mode		p Values			
	Segment-based	Vessel-based	Patient-based	Segment-based	Vessel-based	Patient-based	Segment-based	Vessel-based	Patient-based
TP	55	28	17	62	25	16	_	_	_
TN	583	166	29	566	169	31	_	_	_
FP	16	4	3	14	5	2	_	_	_
FN	6	1	1	7	1	1	_	_	_
Sensitivity (%)	90.2 (79.8—96.3)	96.6 (82.2—99.9)	94.4 (72.7—99.9)	89.9 (80.2—95.8)	96.2 (80.4—99.9)	94.1 (71.3—99.9)	81 (χ²=0.06)	52 (χ²=0.41)	49 (χ²=0.47)
Specificity (%)	97.3 (95.7—98.5)	97.7 (94.1—99.4)	90.6 (75.0—98.0)	97.6 (95.9—98.7)	97.1 (93.4—99.1)	93.9 (79.8—99.3)	92 (χ ² =0.01)	97 (χ²=0.01)	97 (χ²=0.01)
PPV (%)	77.5 (66.0—86.5)	87.5 (71.0—96.5)	85.0 (62.1—96.8)	81.6 (71.0—89.6)	83.3 (65.3—94.4)	89.0 (65.3—98.6)	68 (χ²=0.17)	92 (χ²=0.01)	90 (χ²=0.02)
NPV (%)	98.9 (97.8—99.6)	99.4 (96.7—100)	96.7 (82.8—99.9)	98.8 (97.5—99.5)	99.4 (96.8—100)	96.9 (83.8—99.9)	96 (χ²=0.01)	94 (χ²=0.01)	81 (χ ² =0.06)
Accuracy (%)	96.7 (95.0—97.9)	97.5 (94.2—99.2)	92.0 (80.8—97.8)	96.8 (95.1—98.0)	97.0 (93.4—99.0)	94.0 (79.8—99.3)	98 (χ²=0.01)	97 (χ²=0.01)	94 (χ²=0.01)

FN, false negatives; FP, false positives; NPV, negative predictive value; PPV, positive predictive value; TN, true negatives; TP, true positives.

typically low, ranging between 0.2 and 0.5, which indicates that the table is advanced by less than one detector width during each scanner rotation.⁴ Thus, the same imaged region is exposed during several consecutive rotations of the radiating gantry, which consequently increases the radiation dose.⁴ ¹⁴

Prospectively ECG-gated CT coronary angiography (ie, SAS mode) using single-source, 64-slice and dual-source 64-slice CT systems, has been shown to be associated with radiation doses of 1.2-4.3 mSv, depending on the scanner type and kilovoltage setting used.^{5 6 8} In this study employing second-generation, 128-slice, dual-source CT, the radiation dose was, on average, 1.4 mSv for the SAS mode. As expected, this conforms to previously published studies using the same low-dose technique. The only difference would be an expected reduction of misalignment artefacts when using the broader detector width of 128-slice as compared with 64-slice CT scanners.

As shown in this study, the high-pitch mode further and significantly lowers the radiation dose to <1 mSv. This can be explained by the fact that using high-pitch imaging, 'superfluous' x-rays exposing the entire width of the detector as it enters and leaves the entire arc of projections are applied only once at the beginning and end of the spiral path.^{9 14} With SAS data acquisition, on the other hand, such 'superfluous' exposure occurs for every acquired slice.

Image quality

In the high-pitch mode, data acquisition is completed within one cardiac cycle, using a time window of approximately 250 ms. From the data acquired, cross-sectional images are reconstructed with a temporal resolution of 75 ms, similar to the temporal resolution of the SAS mode. With this mode, the coronary arteries are imaged during slightly different instances in time: while the cranial images are obtained at the beginning of data acquisition, subsequent caudal images display the heart in slightly later time instants within the same cardiac cycle.^{9–11} ¹⁴ Transitions between subsequent images are smooth and small, and since the entire data acquisition is completed within one phase of the cardiac cycle, misalignment (or stair-step) artefacts usually do not occur. In our study, misalignment was found in coronary segments of three patients scanned in the SAS mode but in no patients from the high-pitch mode.

Accuracy of the low-dose protocols

The performance of cardiac CT to diagnose or to exclude morphological CAD has been amply documented.¹ Interestingly,

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the strengths and weaknesses of the modality maintained a fairly robust *pattern* over various scanner generations and scanning protocols. This holds true also for low-dose protocols employing the SAS mode, and similarly, the most recent dosesaving protocol—that is, the high-pitch mode, presented herein. The diagnostic performance of CT coronary angiography is characterised by a high sensitivity and excellent negative predictive value, highlighting the role of the non-invasive modality to reliably exclude coronary stenoses. On the other hand, specificity and even more positive predictive value are only moderate, indicating the limitation of cardiac CT to disclose false-positive results.

Requirements for low-dose cardiac CT

To apply the high-pitch mode, several prerequisites must be fulfilled. First, dual-source geometry is necessary so that projection data can be obtained by the second detector to fill in gaps caused by the fast table motion. Second, temporal resolution must be high to allow single-cycle reconstruction without motion artefacts. Third, the heart rate must be regular because the data acquisition start is triggered by the R-peak of the heart beat that precedes the cardiac cycle in which data are acquired-this is necessary to accelerate the patient table to its maximum speed. Inconstant heart rates would lead to inaccurate positioning of the data acquisition window, with data being acquired either too early in the cardiac cycle (if heart rate decreases) or too late (if heart rate increases). Finally, the highpitch mode requires relatively low heart rates for obtaining motion artefact-free images during a single diastolic period (generally the diastasis). In our study, heart rates were all <70 bpm and were regular, with a resulting diagnostic image quality in 98.9% of the coronary segments.

The SAS mode, in contrast, also requires certain preconditions to be successfully applied. First, the heart rates should be below 60 to 65 bpm when using 64-slice $\rm CT^6$ or <70 bpm when using dual-source $\rm CT$,⁸ to allow for motion artefact-free imaging of the coronary arteries. Second, the heart rate must be regular to obtain an image of the entire coronary tree in the same, preselected cardiac phase (usually in mid-diastole), thus avoiding misalignment (or stair-step) artefacts.

Study limitations

We did not determine the upper body mass index (BMI) limit for the 100 kV protocols. In our patients with a BMI of up to

CT coronary angiography

31.2 kg/m², however, image noise as a reason for non-diagnostic image quality was observed in only two coronary artery segments in the SAS and in one segment in the high-pitch mode group. Furthermore, the upper-limit heart rate for the high-pitch mode was not defined. In the studies of Lell *et al*¹⁴ and Leschka *et al*,¹⁶ patients with heart rates up to 59–60 bpm, respectively, were included. In this study, heart rates ranged up to 70 bpm, but with small heart rate variability, while no obvious reduction in image quality due to blurring or motion artefacts was observed. Certainly, the upper boundaries of the high-pitch mode, both with respect to the average and the variability of heart rate, need to determined in future studies.

CONCLUSION

Both the SAS and the high-pitch mode for dual-source 128-slice CT coronary angiography deliver highly accurate information about the presence or absence of significant coronary stenoses, as defined by CA, at a low radiation dose. The high-pitch mode, as compared with the SAS mode, further lowers the effective radiation doses to levels <1 mSv while maintaining the image quality and high performance of the technique.

Competing interests None.

Patient consent Obtained.

Ethics approval This study was conducted with the approval of the ethics committee of the University Hospital of Zurich (SPUK), Switzerland.

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REFERENCES

- Stein PD, Beemath A, Kayali F, et al. Multidetector computed tomography for the diagnosis of coronary artery disease: a systematic review. Am J Med 2006;119:203-16.
- Alkadhi H. Radiation dose of cardiac CT—what is the evidence? Eur Radiol 2009;19:1311—15.

- Hausleiter J, Meyer T, Hermann F, et al. Estimated radiation dose associated with cardiac CT angiography. Jama 2009;301:500-7.
- Primak AN, McCollough CH, Bruesewitz MR, et al. Relationship between noise, dose, and pitch in cardiac multi-detector row CT. Radiographics 2006;26:1785—94.
- Shuman WP, Branch KR, May JM, et al. Prospective versus retrospective ECG gating for 64-detector CT of the coronary arteries: comparison of image quality and patient radiation dose. Radiology 2008;248:431-7.
- Klass 0, Jeltsch M, Feuerlein S, et al. Prospectively gated axial CT coronary angiography: preliminary experiences with a novel low-dose technique. Eur Radiol 2009;19:829–36.
- Herzog BA, Wyss CA, Husmann L, et al. First head-to-head comparison of effective radiation dose from low-dose 64-slice CT with prospective ECG-triggering versus invasive coronary angiography. *Heart* 2009;95:1656–61.
- Scheffel H, Alkadhi H, Leschka S, et al. Low-dose CT coronary angiography in the step-and-shoot mode: diagnostic performance. *Heart* 2008;94:1132–7.
- Ertel D, Lell MM, Harig F, et al. Cardiac spiral dual-source CT with high pitch: a feasibility study. *Eur Radiol* 2009;19:2357–62.
- Achenbach S, Marwan M, Schepis T, et al. High-pitch spiral acquisition: a new scan mode for coronary CT angiography. J Cardiovasc Comput Tomogr 2009;3:117–21.
- Hausleiter J, Bischoff B, Hein F, et al. Feasibility of dual-source cardiac CT angiography with high-pitch scan protocols. J Cardiovasc Comput Tomogr 2009;3:236–42.
- Lell M, Hinkmann F, Anders K, et al. High-pitch electrocardiogram-triggered computed tomography of the chest: initial results. Invest Radiol 2009;44:728–33.
- Sommer WH, Schenzle JC, Becker CR, et al. Saving dose in triple-rule-out computed tomography examination using a high-pitch dual spiral technique. *Invest Radiol* 2010;45:64–71.
- Lell M, Marwan M, Schepis T, et al. Prospectively ECG-triggered high-pitch spiral acquisition for coronary CT angiography using dual source CT: technique and initial experience. Eur Radiol 2009;19:2576–83.
- Goetti R, Baumüller S, Feuchtner G, et al. High-pitch dual-source CT angiography of the thoracic and abdominal aorta: is simultaneous coronary artery assessment possible? AJR Am J Roentgenol 2010;194:938–44.
- Leschka S, Stolzmann P, Desbiolles L, et al. Diagnostic accuracy of high-pitch dualsource CT for the assessment of coronary stenoses: first experience. Eur Radiol 2009;19:2896–903.
- 17. Diamond GA, Forrester JS. Analysis of probability as an aid in the clinical diagnosis of coronary-artery disease. *N Engl J Med* 1979;300:1350-8.
- Austen WG, Edwards JE, Frye RL, et al. 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* 1975;51:5–40.