

Research article

Improved coronary CT angiography image quality using photon-counting detector CT in SCAPIS reexamination: scan protocol and comparative analysis



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ABSTRACT

Objectives: The Swedish CArdioPulmonary bioImage Study reexamination (SCAPIS reexamination) is the first population-based study to employ coronary CT angiography (CCTA) using photon-counting detector CT (PCD-CT). It includes 15,000 participants from SCAPIS baseline. This work aims to describe the PCD-CT protocol in SCAPIS reexamination, compare diagnostic image quality with energy-integrating detector CT (EID-CT) at SCAPIS baseline, and assess the comparability of Agatston scores and degree of stenosis between the studies.

Methods: The PCD-CT protocol in SCAPIS reexamination is provided. CCTA data from 1,147 participants in SCAPIS reexamination (51% women, age 65 [IQR 61–69]) and 29,554 participants in SCAPIS (52% women, age 58 [54–61]) were analyzed. The image quality in eleven proximal and middle coronary segments was compared, stratified by Agatston score. Agatston scores and stenosis degree were compared in age- and sex-matched samples.

Results: Full diagnostic image quality was more frequent in SCAPIS reexamination (1,036/1,147, 90%) compared with SCAPIS baseline (20,468/26,188, 78%), $p < 0.001$, despite a higher calcium burden (Agatston score 8 [0–106] vs. 0 [0–20]). Of participants with Agatston score > 400 , 89/116, 77%, and 246/945, 26%, had full diagnostic image quality, respectively, $p < 0.001$. Agatston score distributions and stenosis $\geq 50\%$ were similar

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in matched samples ($p = 0.51$ and $p = 0.08$). Of those with $\geq 50\%$ stenosis at SCAPIS baseline, 30% (12/40) were reclassified to $< 50\%$ in SCAPIS reexamination.

Conclusion: The optimized PCD-CT protocol in SCAPIS reexamination provided high image quality, irrespective of Agatston scores, outperforming the EID-CT protocol used at SCAPIS baseline. Agatston scores were comparable, but potential differences in stenosis grading warrant further investigation.

1. Introduction

The Swedish Cardiopulmonary Bioimage Study (SCAPIS) is a population-based prospective study with the central aim of predicting and preventing cardiovascular disease [1]. Between 2013 and 2018, over 30,000 participants aged 50 to 64 years were randomly recruited and extensively characterized, including assessment with cardiac computed tomography (CCT). Subclinical coronary atherosclerosis was common in the SCAPIS baseline examination, with any signs of atherosclerosis found in 42.1% and significant stenosis ($\geq 50\%$) in 5.2% [2].

The SCAPIS reexamination is currently reassessing 50% of the original SCAPIS baseline population. Aims of this ongoing study include describing the progression of coronary atherosclerosis and identifying its determinants and associations with future cardiovascular events, and CCT is a key assessment modality. In the SCAPIS baseline examination, CCT was performed using a dual-source energy-integrating detector CT (EID-CT), which was state-of-the-art at the time. Since then, photon-counting detector CT (PCD-CT) has emerged as a new generation of CT technology that offers higher spatial resolution, reduced image noise, and spectral information.

A key rationale for using PCD-CT in SCAPIS reexamination was that early publications indicated significant advantages in CCT imaging with PCD-CT [3–7], including improved diagnostic quality [3,4,8–10]. The CCT protocol in SCAPIS reexamination has been designed to optimize image quality, enabling detailed plaque characterization and minimizing calcium blooming. To the best of our knowledge, no previous study has published a detailed scan protocol description for PCD-CT together with diagnostic image quality metrics for a large cohort with varying degrees of calcification.

The three aims of the present paper were: (1) to describe the PCD-CT scan protocol in SCAPIS reexamination, (2) to report the diagnostic image quality of PCD-CT in SCAPIS reexamination in relation to Agatston scores and compared with EID-CT at SCAPIS baseline, and (3) to assess the comparability of Agatston scores and stenosis grading between the two studies.

2 Material and methods

SCAPIS was approved as a multicenter study by the ethical review board in Umeå, Sweden (2010–228-31 M), and SCAPIS reexamination was approved by the Swedish Ethical Review Authority (2022–06913-01).

2.1. SCAPIS reexamination study design

SCAPIS reexamination aims to recruit approximately half of the original SCAPIS baseline population ($n = 15,000$) at a median of 8 years after their initial participation. The examination protocol, including detailed functional analyses and imaging of the respiratory and cardiovascular systems, is similar to the SCAPIS baseline protocol, with the exception that carotid ultrasound is not performed. Inclusion in SCAPIS reexamination started in January 2024 and is expected to close in February 2026.

2.2. CCT protocol in SCAPIS reexamination

2.2.1. Administration of drugs and contrast medium

A beta-blocker and sub-lingual glyceryl nitrate are administered to all participants without contraindications. For coronary CT angiography (CCTA), iodine contrast medium (Omnipaque 350 mg I/ml, GE HealthCare, Stockholm, Sweden) is administered with an injection time of 12–16 s. Details regarding drug and iodine contrast administration are provided in the Supplement.

2.2.2. CCT protocol

In SCAPIS reexamination, CCT is performed using PCD-CT equipped with two cadmium telluride detectors (NAEOTOM Alpha, Software version VB10, Siemens Healthineers, Forchheim, Germany). The scan protocol was developed in collaboration with the vendor through an iterative process, systematically testing various scan and reconstruction parameters to achieve optimal image quality at a reasonable radiation dose level. The complete scan protocol and the rationale behind the selected parameters are provided in the Supplement.

Briefly, the CCT protocol consists of two scans. First, a non-contrast coronary artery calcium CT (CAC CT) is performed using either a high-pitch helical or a sequential technique, selected automatically by the CT scanner based on the participant's heart rate and rhythm variability (collimation 144x0.4 mm, 120/140 kV, image quality (IQ) level 19). Images are reconstructed with 3 mm slice thickness at 70 keV and with a quantitative kernel (Qr36).

Subsequently, a contrast-enhanced CCTA is performed using a scan protocol that automatically selects the scan mode – high pitch helical or sequential scan – based on a predefined decision tree, taking into account the automatically calculated Agatston score, heart rate, and rhythm variability. The high-pitch helical mode (144x0.4 mm, 140 kV, IQ level 64) is used in participants with a regular heart rate < 60 and Agatston score = 0. In participants with an Agatston score of 1–99, a sequential scan with the standard detector mode (144x0.4 mm, 140 kV, IQ level 64) is used. In those with an Agatston score of ≥ 100 or with coronary stents, a sequential scan with the ultra-high resolution (UHR) mode is used (96x0.2 mm, 120 kV, IQ level 56). In participants with heart rate > 70 or arrhythmic heartbeat, the scan includes both systolic and diastolic phases (30–80%).

The scan modes and the decision tree are presented in the Supplement.

2.2.3. Image reconstruction

Images are reconstructed using vascular kernels at different sharpness levels: for standard mode Bv44 (always) and Bv56 (if Agatston score > 0), and for UHR mode, Bv48 and Bv64. An additional reconstruction is performed in the spectral postprocessing format (SPP), with a quantitative kernel (Qr44/Qr48). An adjusted protocol for coronary artery bypass grafts is described in the Supplement.

2.3. CCT analysis in SCAPIS reexamination

2.3.1. Readers

CCT analysis is conducted at six study sites by thoracic radiologists or imaging cardiologists with a minimum of level 2 training in accordance with the American College of Cardiology Foundation / American Heart Association Clinical Competence Statement on cardiac CT [11]. Before the study start, all readers participated in a two-day educational

program that included a review of ten example cases. Throughout the study, continuous quality control is maintained via Equalis, Sweden's accredited provider of external quality assessment through recurring reading sessions, in which four readers from each site independently evaluate the same five CCT examinations. These sessions are followed by a results report for each site and a feedback session to discuss any discrepancies in assessments.

2.3.2. Software

Image analysis is performed using the software *Syngo.Via VB80B* (Siemens Healthineers). Results are consecutively entered into an electronic case report form. The readings are performed blinded to the SCAPIS baseline results, and the readers are not allowed to load prior images.

2.3.3. Calcium scoring

Calcium scoring is performed according to the Agatston method [12]. The scoring is automatically conducted by the software using a deep learning-based branch-wise scoring algorithm [13,14]. The reader can apply corrections to the automatic scoring if necessary. Calcium scoring is not performed if artefacts make coronary calcium difficult to delineate.

2.3.4. Plaque analysis

For the reporting of coronary atherosclerosis, the 18 coronary segment model defined by the Society of Cardiovascular Computed Tomography is used [15]. The coronary arteries are analyzed as far distally as possible, considering the technical quality of the scan. Reconstructions with a lower sharpness level (Bv44/Bv48) are used for an anatomical overview and for excluding coronary artery disease. Images with higher sharpness level (Bv56/Bv64) are used for plaque evaluation and stenosis assessment, particularly in the case of calcifications. The quantitative spectral post-processing reconstruction (SPP) is available for problem-solving when reconstruction artifacts are suspected in the Bv-reconstructions.

2.3.5. Non-diagnostic segments

As in SCAPIS baseline, a coronary segment is classified as *non-diagnostic for technical reasons* if artifacts preclude vessel wall and plaque delineation or if parts of the segment are missing in the images. A segment is defined as *non-diagnostic due to calcifications* if the contour between the plaque and lumen cannot be defined due to calcium blooming.

2.3.6. Plaque definitions

A coronary plaque is defined as a well-defined structure with an area of at least 1 mm² in the coronary artery wall, clearly distinguishable from the epicardial fat tissue and from the vessel lumen [16]. For each coronary segment, plaques are classified into one of three categories: i) non-calcified (no calcifications in the segment); ii) calcified (containing high-attenuation tissue on the non-contrast enhanced scan); or iii) partially calcified (segment containing both calcified and non-calcified plaque components).

For each coronary segment containing a plaque, diameter stenosis is graded as one of two categories: <50% or ≥ 50%, following an identical grading protocol to that in SCAPIS baseline. To determine the degree of stenosis of a calcified plaque, the reader is encouraged to use image reconstructions with a sharp kernel (Bv56 or Bv64).

On the case level, the maximum stenosis degree is reported in more detail according to CAD-RADS 2.0 [17], including the reporting of high-risk plaque features, see Supplement.

2.4. Comparison of CCT in SCAPIS reexamination and SCAPIS baseline

2.4.1. Inclusion

In the SCAPIS baseline examination, CCT was performed using a

dual-source EID-CT, Siemens Definition Flash (Siemens Healthineers), with protocol development in collaboration with the vendor. The EID-CT scan was personalized by selecting one of five scan protocols depending on the participant's heart rate and calcifications, as previously reported [2].

In this work, the analyzed data represent reader assessments reported to the SCAPIS database. Data were extracted for the full SCAPIS baseline cohort. From the ongoing inclusion in SCAPIS reexamination, PCD-CT data from a sample of 1,200 individuals were included, 200 from each site, starting from the 101st participant. Participants with coronary stents or coronary artery bypass grafts were excluded.

Comparisons between PCD-CT and EID-CT were performed in three modes: 1) full baseline cohort vs. reexamination sample; 2) age- and sex-matched samples from baseline and reexamination (20:1); and 3) paired samples from baseline and reexamination, see Fig. 1. Studies with missing data were excluded from all analyses separately.

2.4.2. Diagnostic image quality

The diagnostic image quality of PCD-CT in SCAPIS reexamination and EID-CT at the SCAPIS baseline examination was compared in eleven proximal and middle coronary segments (segments 1–3, 5–7, 9, 11–13, and 17). In the baseline examination, the image quality for these eleven segments was compulsory to report from 2014 onward, resulting in the availability of 26,188 CCTA examinations for the comparison [2]. Segment-level reports of non-diagnostic segments were retrieved from the database.

Full diagnostic image quality for CCTA was defined as having no non-diagnostic segments among the eleven proximal and middle coronary segments. The proportion of examinations with full diagnostic image quality was computed, stratified for the Agatston score and in the matched samples.

2.4.3. Comparability of Agatston scores and stenosis degree

The comparability of Agatston scores between PCD-CT in SCAPIS reexamination and EID-CT at the SCAPIS baseline examination was analyzed by comparing the distribution of Agatston scores in the matched samples.

In the matched samples, the proportions of individuals with any stenosis ≥ 50% were computed in SCAPIS reexamination and baseline. In the paired samples, the presence of any stenosis ≥ 50% at baseline and reexamination was cross-tabulated, and the number of participants with stenosis ≥ 50% at baseline that was downgraded to < 50% in the reexamination was computed.

2.5. Statistics

Baseline data were reported as median (interquartile range, IQR). Proportions were reported with 95% confidence intervals (CI). Comparisons were performed using the Wilcoxon rank-sum and chi-squared tests, as appropriate. No formal correction for multiple testing across subgroup analyses was applied because the emphasis was on effect sizes and their CIs rather than on dichotomous p-value rejection. Wilcoxon rank-sum test and the Kolmogorov-Smirnov tests were used to compare the distribution of Agatston scores. The McNemar test was used for cross-tabulation of stenosis evolution.

Statistics were computed using MATLAB R2024a (The Mathworks). For the calculation of effective radiation dose, a conversion factor of 0.0204 mSv/(mGycm) was used [18].

3 Results

Patient characteristics and radiation dose for included participants in the SCAPIS full cohort at baseline, in the SCAPIS reexamination sample, and sex- and age-matched samples are detailed in Table 1. The interval between CT in baseline and reexamination for included participants was 7.4 ± 1.0 years.

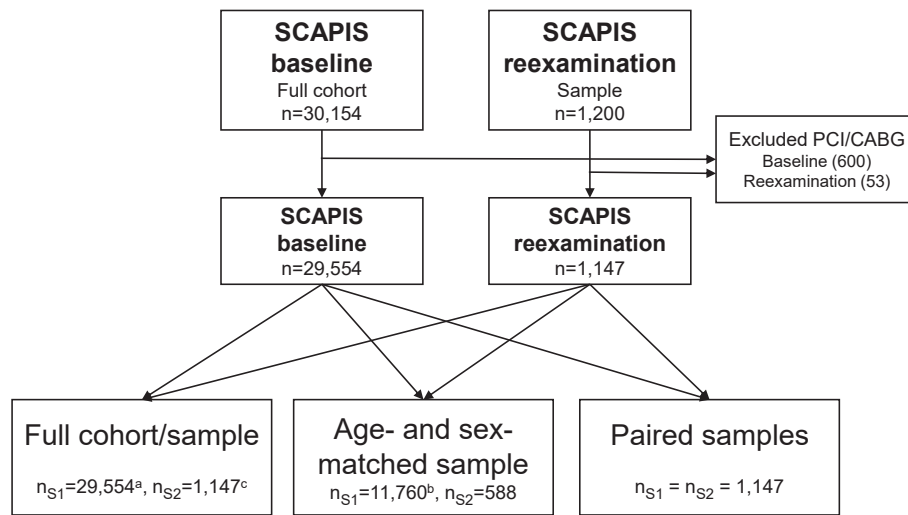


Fig. 1. Included participants. Analyses in three modes with the number of participants before exclusion because of missing data. n_{S1} – size of SCAPIS baseline cohort/sample. n_{S2} – size of the SCAPIS reexamination sample. PCI = percutaneous coronary intervention, CABG = coronary artery bypass grafting. All participants with PCI and/or CABG in SCAPIS baseline or reexamination were excluded. ^a CACS missing in 763/29,554 (28,791 valid), complete CCTA data missing in 3,366/29,554 (26,188 valid). ^b CACS missing in 93/11,760 (11,667 valid), complete CCTA data missing in 1,272/11,760 (10,488 valid). Data on any stenosis missing in 946/11,760 (10,814 valid). ^c CACS missing in 2/1,147 (1,145 valid), no missing data in CCTA.

Table 1
Participant characteristics and radiation dose.

	Baseline (EID). Full cohort, n = 29,554	Reexamination (PCD) Sample, n = 1,147	p-value*	Baseline (EID). Matched sample, n = 11,760	Reexamination (PCD). Matched sample, n = 588	p-value*
Age (years)	57.5 (53.7–61.2)	64.9 (61.0–68.6)	<0.001	61.3 (59.2–63.4)	61.3 (59.2–63.4)	0.97
Sex (M/F)	47.9%/52.1%	49.4%/50.6%	0.34	50.3%/49.7%	50.3%/49.7%	1.0
Weight (kg)	79.0 (68.7–90.0)	78.9 (69.2–89.9)	0.39	79.0 (68.7–89.7)	80.5 (69.9–92.4)	0.016
BMI (kg/m ²)	26.3 (23.9–29.4)	26.6 (24.1–29.7)	0.10	26.4 (24.0–29.3)	26.7 (24.1–29.7)	0.22
CAC CT CTDI (mGy)	1.1 (0.9–2.1)	1.4 (1.2–1.8)	<0.001	1.1 (0.9–2.2)	1.4 (1.2–1.8)	<0.001
CAC CT DLP (mGycm)	21 (17–29)	28 (23–34)	<0.001	21 (17–30)	28 (23–34)	<0.001
CAC CT effective dose (mSv)	0.4 (0.3–0.6)	0.6 (0.5–0.7)	<0.001	0.4 (0.3–0.6)	0.6 (0.5–0.7)	<0.001
CCTA CTDI (mGy)	6.0 (4.4–7.9)	10.6 (4.0–15.5)	<0.001	6.1 (4.6–8.0)	9.8 (3.3–14.5)	<0.001
CCTA DLP (mGycm)	79 (56–105)	134 (70–196)	<0.001	80 (59–106)	126 (60–187)	<0.001
CCTA effective dose (mSv)	1.6 (1.1–2.1)	2.7 (1.4–4.0)	<0.001	1.6 (1.2–2.2)	2.6 (1.2–3.8)	<0.001

Note: Effective dose is calculated with conversion factor 0.0204 mSv/(mGycm) *p-values for Wilcoxon rank sum test/chi-squared test. Values presented as median (inter-quartile range) or percentages. CAC – coronary artery calcium. CCTA – coronary CT angiography. CTDI – Volume CT dose index. DLP – Dose length product.

Table 2
Per segment non-diagnostic rates.

Coronary Segment	Non-diagnostic Calcium (EID) n = 26,188	Non-diagnostic Calcium (PCD) n = 1,147	p-value*	Non-diagnostic Technical (EID) n = 26,188	Non-diagnostic Technical (PCD) n = 1,147	p-value*	Non-diagnostic Total (EID) n = 26,188	Non-diagnostic Total (PCD) n = 1,147	p-value*
1. Proximal RCA	145 (0.6%)	4 (0.3%)	0.05	812 (3.1%)	14 (1.2%)	<0.001	957 (3.7%)	18 (1.6%)	<0.001
2. Mid RCA	214 (0.8%)	1 (0.1%)	<0.001	1,455 (5.6%)	21 (1.8%)	<0.001	1,669 (6.4%)	22 (1.9%)	<0.001
3. Distal RCA	120 (0.5%)	2 (0.2%)	0.008	1,206 (4.6%)	24 (2.1%)	<0.001	1,326 (5.1%)	26 (2.3%)	<0.001
5. Left main	32 (0.1%)	1 (0.1%)	0.53	377 (1.4%)	4 (0.3%)	0.002	409 (1.6%)	5 (0.4%)	0.002
6. Proximal LAD	404 (1.5%)	3 (0.3%)	<0.001	562 (2.1%)	14 (1.2%)	0.001	966 (3.7%)	17 (1.5%)	<0.001
7. Mid LAD	617 (2.4%)	4 (0.3%)	<0.001	941 (3.6%)	16 (1.4%)	<0.001	1,558 (5.9%)	20 (1.7%)	<0.001
9. Diagonal 1	443 (1.7%)	13 (1.1%)	<0.001	1,521 (5.8%)	16 (1.4%)	<0.001	1,964 (7.5%)	29 (2.5%)	<0.001
11. Proximal LCx	199 (0.8%)	3 (0.3%)	0.003	775 (3.0%)	14 (1.2%)	<0.001	974 (3.7%)	17 (1.5%)	<0.001
12. Obtuse Marginal 1	238 (0.9%)	4 (0.3%)	<0.001	1,625 (6.2%)	24 (2.1%)	<0.001	1,863 (7.1%)	28 (2.4%)	<0.001
13. Mid and distal LCx	157 (0.6%)	1 (0.1%)	<0.001	1,846 (7.0%)	16 (1.4%)	<0.001	2,003 (7.6%)	17 (1.5%)	<0.001
17. Ramus intermedius	144 (0.5%)	1 (0.1%)	0.003	922 (3.5%)	3 (0.3%)	<0.001	1,066 (4.1%)	4 (0.3%)	<0.001

Note: * p-values for chi-squared tests. Coronary artery segment numbering according to Society of Cardiovascular Computed Tomography. EID – Energy-integrating detector protocol in SCAPIS baseline. PCD – photon-counting detector protocol in SCAPIS reexamination.

3.1. Diagnostic image quality of coronary CT angiography

In the full SCAPIS baseline cohort and the SCAPIS reexamination sample, the number of CCTA with full diagnostic image quality was 20,468/26,188 (78% [95% CI 77.7–78.7%]) using EID-CT and 1,036/1,147 (90% [88.5–92.0%]) using PCD-CT, respectively, $p < 0.001$. Among non-diagnostic studies, the median (IQR) number of non-diagnostic segments was 2 (1–3) at SCAPIS baseline and 1 (1–2) at reexamination. Segment-level non-diagnostic rates are reported in Table 2.

In the age- and sex-matched samples, 7,811/10,488 (74% [73.6–75.3%]) and 535/588 (91% [88.4–93.2%]) of CCTA had full diagnostic image quality at SCAPIS baseline and in the SCAPIS reexamination sample, respectively, $p < 0.001$.

The proportion of studies with full diagnostic image quality was significantly higher using PCD-CT compared to EID-CT, irrespective of Agatston scores, with a more pronounced difference with increasing Agatston scores, see Fig. 2. The PCD-CT diagnostic image quality was comparatively stable across Agatston scores, while a marked decline in image quality was observed with EID-CT.

In the SCAPIS reexamination sample, full diagnostic image quality with PCD-CT was seen in 439/474 (93%) and 154/177 (87%) individuals with Agatston scores of 0 and 100–399, respectively. With EID-CT at SCAPIS baseline, full diagnostic image quality was seen in 13,880/15,711 (88%) and 1,061/2,111 (50%) participants with Agatston scores of 0 and 100–399, respectively. In participants with severe calcifications (Agatston score ≥ 400), 77% of CCTA had full diagnostic quality in

SCAPIS reexamination compared with 26% at SCAPIS baseline, $p < 0.001$. Fig. 3 shows an example of CCTA in the same individual using EID-CT at the SCAPIS baseline examination and PCD-CT in the reexamination.

3.2. Comparability of Agatston scores and stenosis degree

Agatston scores for the full cohort and matched samples are reported in Table 3. The distribution of Agatston scores in the matched cohorts was similar (Fig. 4). Wilcoxon rank-sum test for equal medians and Kolmogorov-Smirnov test for equal distributions yielded non-significant results, $p = 0.85$ and $p = 0.51$, respectively, supporting that Agatston scores calculated using EID-CT and PCD-CT are comparable.

In the matched samples, there was no difference in the proportion of participants with any reported stenosis $\geq 50\%$ between EID-CT and PCD-CT; 7.5% (814/10,814) and 9.5% (56/588), respectively, $p = 0.08$. The proportion of participants with any calcified stenosis $\geq 50\%$ was 6.4% (687/10,814), and 7.8% (46/588), respectively, $p = 0.16$. The proportion of participants with any non-calcified stenosis $\geq 50\%$ was 1.8% (191/10,814), and 2.0% (12/588), respectively, $p = 0.62$.

Cross-tabulation of any stenosis $\geq 50\%$ in the paired sample is shown in Fig. 5. Among participants with reported stenosis at the SCAPIS baseline examination, 30% (12/40) were downgraded to $< 50\%$ in SCAPIS reexamination.

4 Discussion

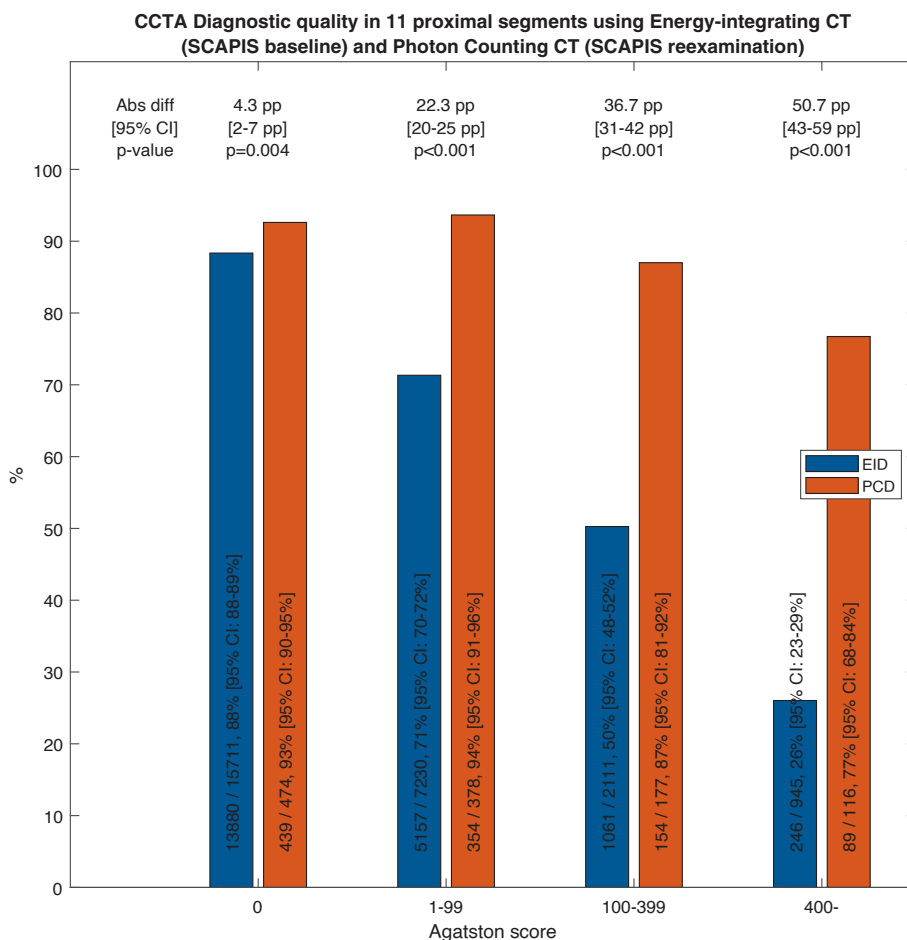


Fig. 2. Proportion of studies with full diagnostic quality in 11 proximal and middle segments stratified for the Agatston score. Ultra-high resolution mode was applied in cases with an Agatston score of > 100 in the reexamination. Out of 29,554 participants included in SCAPIS baseline, 3,366 had incomplete CCTA data and an additional 191 had missing CACS, resulting in $n = 25,997$. Two participants in SCAPIS reexamination had missing CACS, $n = 1,145$. pp – percentage points.

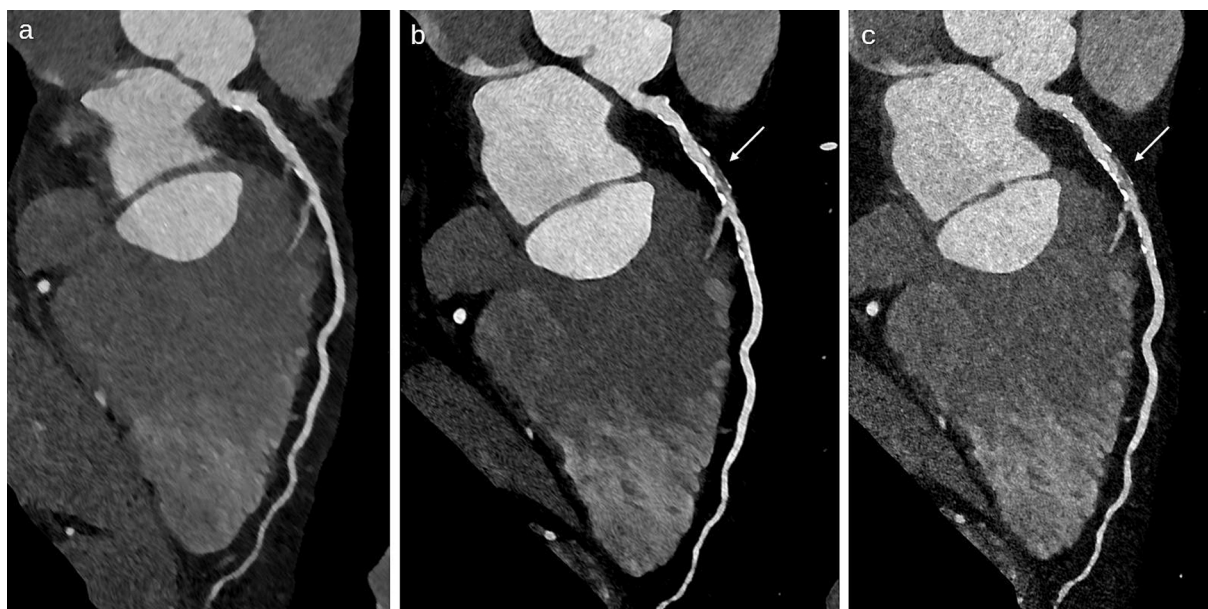


Fig. 3. Curved multiplanar reformats of LAD in a male study participant examined at age 52 in the SCAPIS baseline examination (a) and in the SCAPIS reexamination at age 63 (b, c). Images are reconstructed using standard reconstruction at baseline, I26f/6 (a), and ultra-high resolution mode in the reexamination, Bv48 (b), and Bv64 (c). There is a marked progression of atherosclerosis with a severe stenosis in a partially calcified plaque (arrow). The Agatston score increased from 95 to 1362 between the two studies.

Table 3
Comparability of Agatston scores.

	Baseline (EID) Full cohort, n = 28,791 ^a	Reexamination (PCD) Sample, n = 1,145 ^b	p-value	Baseline (EID) Matched sample, n = 11,667 ^a	Reexamination (PCD) Matched sample, n = 588 ^b	p-value
Agatston score	0 (0–20)	8 (0–106)	<0.001 ^c	1 (0–49)	0.1 (0–50)	0.85 ^c /0.51 ^d

Note: ^a CACS missing in 763/29,554 and 93/11,760 participants in SCAPIS baseline full cohort and matched sample, respectively. ^b CACS missing in 2/1,147 and 0/588 participants in SCAPIS reexamination sample and matched sample, respectively. P-values for ^c Wilcoxon rank sum test, ^d Kolmogorov-Smirnov test. Values are presented as median (inter-quartile range).

SCAPIS reexamination is the first large population-based imaging study utilizing PCD-CT. This publication presents the PCD-CT scan protocol in SCAPIS reexamination with corresponding metrics of diagnostic image quality. We found that the proportion of fully diagnostic examinations in SCAPIS reexamination was higher than at the SCAPIS baseline examination (90% vs. 78%) despite the older sample population with an increased coronary calcification burden, with the most substantial benefit in the case of extensive calcifications.

To optimize calcium imaging in SCAPIS reexamination, participants with an Agatston score of ≥ 100 were examined using the UHR mode, which has previously been demonstrated to reduce calcium blooming [3,5,19]. The differences in image quality between PCD-CT and EID-CT became more pronounced with increasing Agatston scores, reflecting the higher spatial resolution afforded by PCD-CT and the more precise delineation of calcified plaques [8,10]. With respect to translating the present results from CCTA from the cross-sectional SCAPIS study into clinical value, the most important finding is the consistently high diagnostic image quality observed in participants with mild-to-moderate coronary calcifications, who represent the typical patients referred for CCTA with a low-to-intermediate clinical likelihood of coronary artery disease.

In the context of a population-based study, a potential issue with evolving CT technology is the comparability. Previous studies have demonstrated a high degree of correlation between Agatston scores calculated using EID-CT and PCD-CT [20,21]. Although no patient-level comparison could be made in the present study due to the 8-year interval between the baseline examination and the reexamination, no significant

differences were observed in Agatston scores or presence of stenosis $> 50\%$ between sex- and age-matched groups. On the other hand, 30% of participants with a reported diameter stenosis $> 50\%$ at the SCAPIS baseline examination were downgraded to $< 50\%$ in SCAPIS reexamination. However, this paired analysis is limited by the small number of stenoses reported at baseline in the sample (n = 40). In previous studies, visual estimates of coronary artery luminal stenosis were lower with PCD-CT compared with EID-CT [8,10,22]. One possible explanation is decreased calcium blooming; however, considering the long length of follow-up in the study, other causes, such as plaque reorganization due to statin treatment, cannot be excluded [23].

The use of PCD-CT in SCAPIS reexamination afforded several advantages. The improved diagnostic quality of PCD-CT, particularly in cases with calcifications, is a major benefit. With consistent virtual monoenergetic reconstructions, the images are optimized for plaque characterization. In contrast, plaque characterization with EID-CT can be challenging due to tube voltage-dependent variations in luminal and plaque attenuation [24]. Furthermore, the collected PCD-CT spectral information is expected to be an important future resource, enabling material decomposition or perfusion analysis [25].

While the main aim of the present paper is to describe the PCD-CT scan protocol and image quality, there are several limitations in the analysis comparing Agatston scores and stenosis degree in the two studies. Although sex- and age-matched samples were compared, other differences affecting risk factors for cardiovascular disease initiated by findings in SCAPIS baseline, such as statin treatment, cannot be controlled for. By design, a higher radiation dose was used in SCAPIS

Photon Counting and Energy-integrating Agatston Score matched for age and sex

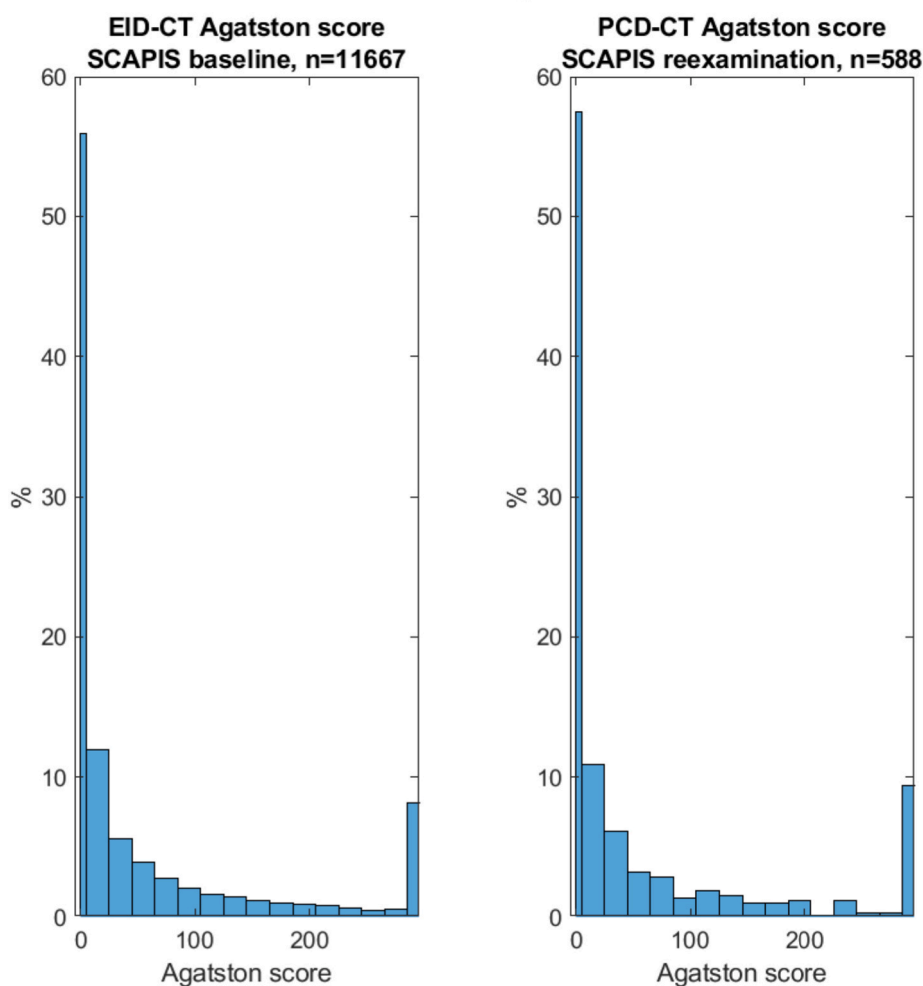


Fig. 4. Distribution of Agatston scores in sex- and age-matched samples in the SCAPIS baseline examination (left, CACS missing in 93/11,760 participants) and the SCAPIS reexamination (right, no missing data). Agatston scores above 300 have been clustered.

reexamination to optimize image quality with future use of spectral reconstructions in mind, and the higher radiation dose contributed to the better image quality. A further limitation is the small number of participants with coronary stenosis > 50%. Furthermore, since only eleven coronary segments were compulsory to report, difference in performance in distal coronary segments cannot be studied. Additionally, the effects of the differences in scanner technology and reader performance between the two studies cannot be separated. CCTA has become a routine diagnostic method, and the readers in the reexamination likely had more clinical CCTA experience. To further assess comparability between the two CCT modalities, an ongoing study is re-evaluating a subgroup of SCAPIS reexamination participants using both PCD-CT and EID-CT with the protocols applied at reexamination and baseline. The study is designed to assess differences in plaque detection and stenosis grading, intra- and inter-reader agreement and may also be used to explore differences in quantitative plaque parameters between the two protocols.

In conclusion, the optimized PCD-CT protocol in SCAPIS reexamination provided high diagnostic image quality, irrespective of Agatston scores, outperforming the EID-CT protocol used at SCAPIS baseline. Agatston scores were comparable, but potential differences in stenosis grading warrant further investigation.

CRediT authorship contribution statement

Mats Lidén: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Gusten Nyberg:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Marie-Louise Aurumskjöld:** Writing – review & editing, Investigation. **Tomasz Baron:** Writing – review & editing, Investigation. **Göran Bergström:** Writing – review & editing, Funding acquisition, Conceptualization. **Lilian Henriksson:** Writing – review & editing, Writing – original draft, Investigation. **Tomas Jernberg:** Writing – review & editing, Funding acquisition, Conceptualization. **Marit Johansson:** Writing – review & editing, Writing – original draft, Investigation. **David Lind:** Writing – review & editing, Investigation. **Henrik Löfmark:** Writing – review & editing, Investigation. **Andrei Malinovschi:** Writing – review & editing, Funding acquisition, Conceptualization. **Anders Persson:** Writing – review & editing, Funding acquisition, Conceptualization. **Patrik Nowik:** Writing – review & editing, Investigation. **Adrian Pistea:** Writing – review & editing, Investigation. **Monica Segelsjö:** Writing – review & editing, Investigation. **Franciska Wikner:** Writing – review & editing, Investigation. **Mårten Sandstedt:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Erika Fagman:** Writing – review &

Cross-tabulation - any stenosis in SCAPIS baseline and reexamination

		Baseline any stenosis >50%	
		YES	NO
Reexamination any stenosis >50%	YES	28	132
	NO	12	929

Fig. 5. Cross-tabulation of participants with any coronary stenosis $\geq 50\%$ in the paired cohort. Missing data in SCAPIS baseline or reexamination in 46/1,147 (1,101 valid). The proportion of participants with stenosis in the SCAPIS baseline examination whose degree of stenosis was downgraded in the SCAPIS reexamination was 30% (12/40). 83% (132/160) with stenosis in the SCAPIS reexamination did not have any stenosis $\geq 50\%$ at baseline ($p < 0.001$).

editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

One author (P Nowik) is an employee and one author (M Segelsjö) is an external employee of Siemens Healthineers Sweden. These authors did not have control over the data at any point during the study. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ejrad.2026.112920>.

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