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Quantification of Coronary Artery Stenosis in Very-High-Risk Patients Using Ultra-High Resolution Spectral Photon-Counting CT

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Objective: Development of spectral photon-counting computed tomography (SPCCT) for ultra-high-resolution coronary CT angiography (CCTA) has the potential to accurately evaluate the coronary arteries of very-high-risk patients. The aim of this study was to compare the diagnostic performances of SPCCT against conventional CT for quantifying coronary stenosis in very-high-risk patients, with invasive coronary angiography (ICA) as the reference method.

Materials and Methods: In this prospective institutional review board–approved study, very-high-risk patients addressed for ICA following an acute coronary syndrome were consecutively included. CCTA was performed for each patient with both SPCCT and conventional CT before ICA within 3 days. Stenoses were assessed using the minimal diameter over proximal and distal diameters method for CCTA and the quantitative coronary angiography method for ICA. Intraclass correlation coefficients and mean errors were assessed. Sensitivity and specificity were calculated for a >50% diameter stenosis threshold. Reclassification rates for conventional CT and SPCCT were assessed according to CAD-RADS 2.0, using ICA as the gold standard.

Results: Twenty-six coronary stenoses were identified in 26 patients (4 women [15%]; age 64 ± 8 years) with 19 (73%) above 50% and 9 (35%) equal or above 70%. The median stenosis value was 64% (interquartile range, 48%–73%). SPCCT showed a lower mean error (6% [5%, 8%]) than conventional CT (12% [9%, 16%]). SPCCT demonstrated greater sensitivity (100%) and specificity (90%) than conventional CT (75% and 50%, respectively). Ten (38%) stenoses were reclassified with SPCCT and one (4%) with conventional CT.

Conclusions: In very-high-risk patients, ultra-high-resolution SPCCT coronary angiography showed greater accuracy, sensitivity, and specificity, and led to more stenosis reclassifications than conventional CT.

Key Words: ultra-high resolution, very-high-risk patients, spectral photon-counting CT, coronary arteries, stenosis

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Coronary computed tomography angiography (CCTA) is being increasingly performed, particularly in low-to-intermediate risk patients, owing to advancements in CT-scanning technology. It is noninvasive and often recommended as a first-line method for assessing coronary artery disease (CAD).[1] Compared with the gold standard for detecting CAD with invasive coronary angiography (ICA), it has a high negative predictive value as well as high sensitivity with good correlation between the 2 methods.[2,3] In CCTA, the diameter of coronary lumen stenoses is assessed and reported using the CAD-RADS classification, which describes the severity of stenosis, plaque burden, and associated high-risk plaque features.[4] Nonetheless, CCTA is still limited by current CT technologies equipped with energy integrating detectors (EIDs), especially in high-to-very-high-risk patients with advanced coronary disease, where it is not routinely recommended.[5,6] This is explained by an achievable spatial resolution, which is insufficient to accurately evaluate stenosis, particularly around highly dense materials such as calcification or stents.

To overcome this limitation, spectral photon-counting computed tomography (SPCCT) systems have recently been introduced at the clinical or prototype stage.[7–17] These systems are equipped with new energy-resolving spectral photon-counting detectors, which facilitate ultra-high resolution (UHR) imaging with an isotropic spatial resolution of up to 250 μm, while offering greater x-ray dose efficiency.[18] Altogether, they have the potential to further improve the performance of CCTA, especially in challenging cases like very-high-risk patients.[19] However, knowledge of their performance in this difficult population is still scarce.

We therefore compared the diagnostic performances of SPCCT against conventional CT in CCTA for quantifying coronary stenosis in very-high-risk patients, using ICA as the reference method.

METHODS

Study Design and Population

This prospective, single-center study was conducted from February 2021 to December 2022 at a tertiary cardiothoracic university hospital (Hôpital Louis Pradel, Hospices Civils de Lyon, France). The study was approved by the local ethical committee (SPEQUA study, Hospices Civils de Lyon, approval number: 2019-A02945–52). All patients had provided written informed consent. We consecutively included all patients referred for ICA following an acute coronary syndrome. For each patient, coronary stenoses detected on ICA were included and compared with conventional CT and SPCCT, using ICA as a gold standard. Patients <18 years, with a contraindication for iodinated contrast media injection, or renal failure with eGFR <30 mL/min were excluded. Note that 1 patient was reported in a previous study.[20] CCTA was performed using conventional CT and

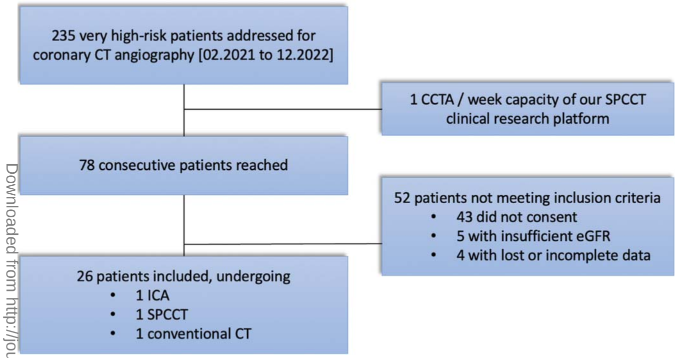

FIGURE 1. Study flowchart. CCTA, coronary CT angiography; ICA, invasive coronary angiography; SPCCT, spectral photon-counting CT.

SPCCT within 3 days before ICA (Fig. 1). Patient characteristics, coronary artery calcium (CAC) scores, and cardiovascular risk factors according to the 2021 ESC guidelines were assessed[21] and reported in Table 1. All patients included were considered as very-high-risk according to the 2021 ESC Guidelines, due to the presence of acute coronary syndromes.

SPCCT and Conventional CT Systems

CCTA was performed using CT systems from the same vendor (Philips Healthcare, the Netherlands). Conventional CT systems consisted of either 4-cm (iQon CT) or 8-cm (CT7500) collimation dual-energy dual-layer CT systems equipped with EIDs. SPCCT consisted of a 2-cm collimation clinical prototype (not yet FDA approved) equipped with a cadmium-zinc-telluride single layer photon-counting detector, with a pixel pitch of 275×275 μm^2 at the isocenter[22] (Table 2).

CT Acquisition and Reconstruction Protocols

A coronary CTA protocol was performed for both systems, using ECG-gating in retrospective mode, helical image acquisition, and a 60-bpm target heart rate. Oral beta-blockers (esmolol chlorohydrate [Esmocard; Orpha Devel Handels Vertriebs]) and sublingual nitroglycerine (Natispray; Teofarma) were used when deemed necessary. Depending on the patient's weight (80 kg cutoff), 65 mL to 75 mL of iomeprol (400 mg/mL; Iomeron; Bracco) were injected at a rate of 5 mL/s, followed by a saline flush. Bolus tracking was used with the conventional CT system, with a region of interest in the descending aorta and a 110 HU threshold. Due to the absence of bolus tracking using SPCCT, we used a bolus test using 20 mL of iomeprol first injected at 5 mL/s, followed by a 20-mL saline flush of 20 mL at 4 mL/s. For both conventional CT and SPCCT, images were acquired at 120 kVp. For SPCCT, 255 and 333 mAs were used for body mass index (BMI) <30 and >30, respectively, according to a previous study.[19] Automatic exposure control was used for conventional CT, with a 28 DoseRight index (target current: 255 mAs; average adult with a water equivalent diameter of 29 cm).

Data were reconstructed between the mid-diastolic and systolic phases (40%–78% of the RR interval) of the cardiac cycle using a 220-mm field of view. Matrix size was increased from 512 to 1024 for SPCCT, and section thickness was decreased from 0.67 mm to 0.25 mm for SPCCT to convey its intrinsic spatial resolution capabilities, as in a previous study.[19] These parameters produced UHR images with a voxel size of 0.25 (z) · 0.21 (x) · 0.21 (y) mm for SPCCT, which is close to the detector's pixel size at the isocenter.[7] Reconstruction parameters are summarized in Table 2.

ICA System

The coronary angiography system was a commercially available Infinix C-arm system (Toshiba Medical, Nasu, Japan). ICA was performed by the hospital's team of experienced cardiologists, using standard techniques and standard projection planes.

ICA and CT Images Analysis

For ICA data, images were independently reviewed by 2 blinded experienced senior cardiologists (AM and ME with 20 years of experience in ICA). Stenoses were measured manually. Stenosis values were averaged between the 2 readers. A traditional stenosis thresholds definition was used, with <50% stenoses defined as mild, 50%–69% as moderate, and ≥70% as severe.[23] Although this study focus on hemodynamically significant (≥50% stenoses), mild stenoses were also included to account for a potential overestimation with CT evaluation. Images were reviewed on a clinical workstation (CAAS Workstation 8.5 [Pie Medical Imaging]). Coronary stenoses were assessed using the conventional QCA methodology. The location of stenosis was described using the revised 17-segment American Heart Association model.[24]

For CT systems data, images were independently reviewed by 2 blinded experienced radiologists (GF, SAS-M with 4 and 7 years of experience in cardiac imaging, respectively). Readers were blinded to the type of CT system and patient identity. Window-level adjustments were allowed. Coronary arteries were assessed in random order after centerline reconstructions, in straight curved planar reconstructions, and cross-sectional views on a clinical workstation (Intellispace Portal; Philips Healthcare, the Netherlands). Stenoses were measured manually and quantified using the CORE-64 methodology for proximal and distal diameters before and after the stenosis,[3] with the following formula:

$$\frac{Avg.of\ proximal\ and\ distal\ diameters\text{–}minimal\ lumen\ diameter}{Avg.of\ proximal\ and\ distal\ diameters}$$

Stenosis values were averaged between the 2 readers but also assessed individually. Stenoses were then further classified using the CAD-RADS 2.0 classification system.[4] Stenosis reclassification rates were assessed for SPCCT versus conventional CT and conversely, using ICA stenosis values as a reference. Finally, the performance of SPCCT versus conventional CT was assessed for low (<300) versus high (>300) coronary calcium scores.

TABLE 1. Population Characteristics

Parameter	Value
Patients (n)	26
Men (n)	22 (84)
Women (n)	4 (16)
Age (y)	64 ± 8
Weight (kg)	79 ± 12
BMI (kg/m^2)	27 ± 4
Hypertension	17 (65)
Diabetes	7 (27)
Hyperlipidemia	13 (50)
Smoking	14 (53)
Acute coronary syndrome	26 (100)
Agatston calcium score	739 ± 783 (min: 70, max: 2404)
Coronary stenosis	26
CAD-RADS 0	0
CAD-RADS 1	0
CAD-RADS 2	8 (30)
CAD-RADS 3	8 (30)
CAD-RADS 4	10 (38)

Data are expressed as means ± SD or n (%) unless otherwise specified.
BMI, body mass index.

TABLE 2. Acquisition and Reconstruction Parameters

Parameter	Conventional CT	SPCCT
Tube voltage (kVp)	120	120
Tube current (mAs)	255	255 for BMI < 30, 330 for higher BMI
Dose modulation	Dose right index of 28 (255 mAs as reference)	No modulation
Rotation time (s/rot)	0.27	0.33
Pitch	0.16	0.32
Collimation (mm)	64 × 0.625 (iQonCT) 128 × 0.625 (CT7500)	64 × 0.275
Focal spot (mm)	Standard (1.1 × 1.2)	Small (0.6 × 0.7)
FOV (mm)	220	220
Matrix size (pixels)	512 × 512	1024 × 1024
Slice thickness (mm)	0.67	0.25
Reconstruction kernel	XCB	Detailed 2
Iterative reconstruction	iDose[4] 6	iDose[4] 6

BMI, body mass index; FOV, field of view.

Statistics

Statistical analysis was performed using SPSS Statistics, version 26.0 (SPSS Inc, Chicago, IL). Normality for variables was assessed using Shapiro-Wilk tests. Continuous variables were expressed as means ± standard deviation (SD) or median ± interquartile range. To assess reproducibility between ICA and CCTA, we calculated the intraclass correlation coefficient (ICC), 2-way mixed effects, absolute agreement, and average measurements. Correlation was classified as excellent (ICC > 0.9), good (0.9 > ICC > 0.75), moderate (0.75 > ICC > 0.5), or poor (ICC < 0.5), based on the 95% confidence interval (CI) of the ICC estimate. Mean errors with a 95% CI were assessed for conventional CT and SPCCT using ICA as a reference. The percentage agreement for stenosis between ICA and both SPCCT and conventional CT was determined using a Bland-Altman analysis. Weighted kappa values were assessed for CAD-RADS categories between readers, and agreement was interpreted as follows: <0.20, poor; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, good; and 0.81–1.00, very good. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy as well as receiver operator characteristic curves and the corresponding area under the curve (AUC) were calculated for stenosis above or below 50% and 70% significance thresholds, for both SPCCT and conventional CT as well as for standard and intention-to-diagnose analyses including noninterpreatable segments as positive. The interreader ICC was also assessed for the diameter of stenosis, both for conventional CT and SPCCT. Differences in radiation doses were compared using a Wilcoxon rank sum test. Differences between conventional CT and SPCCT performances were compared using a χ^2 test. A P value <0.05 was considered as statistically significant.

Radiation Dose Study

Dose-length product and volume CT dose index (CTDI) were recorded. Further explanations on the technical difference between doses are provided in the Supplemental Methods, http://links.lww.com/RLI/A946, section.

RESULTS

Study Population

A total of 26 very-high-risk patients were included (mean age 64 ± 8 years, 4 women [15%], BMI 27 ± 4 kg/m^2). The population's Agatston score was 739 ± 783 (SD) (Table 1). Fifty-two stenoses were identified, 13 [25%] of which were in the right coronary artery, 31 [59%] in the left ascending coronary artery, 7 [13%] in the circumflex artery, and 1 [2%] in the left main trunk. Eight [15%] stenoses were excluded from the analysis due to motion artifacts in the conventional CT images, 17 [32%] stenoses were excluded due to motion artifacts in SPCCT, and 7 [13%] stenoses were excluded due to patients being treated between the 2 CT examinations. Twenty-six stenoses were finally included, quantified as 60% ± 17% (min: 27%, max: 88%) on ICA. Nineteen (73%) stenoses were above the 50% threshold and 9 (35%) were equal or above 70%, whereas the most prevalent class was CAD-RADS 4 (10 [38%]) (Table 1).

Comparative Analyses

Excellent correlation was found between SPCCT and ICA (ICC = 0.94 [95% CI, 0.86, 0.98], P < 0.001), whereas a moderate correlation was found between conventional CT and ICA (ICC = 0.65 [95% CI, 0.21, 0.84], P = 0.006). A moderate correlation was found between SPCCT and conventional CT (ICC = 0.69 [95% CI, 0.31, 0.86], P = 0.002) (Table 3). SPCCT showed a lower mean error with an average value of 6% [5%, 8%], compared with conventional CT with an average value of 12% [9%, 16%].

The Bland-Altman analysis showed greater agreement between ICA and SPCCT (mean 3% ± 7% [95% CI, −10%, 16%], limits of agreement, 13%, P < 0.001) compared with ICA and conventional CT (mean 0% ± 16% [95% CI, −30%, 30%], limits of agreement, 30%, P < 0.001) (Fig. 2 and Table 3).

CAD-RADS Classification

SPCCT showed greater CAD-RADS stenosis classification accuracy with 8 out of 8 (100%) stenoses correctly classified as CAD-RADS 2, 7 out of 8 (88%) as CAD-RADS 3, and 6 out of 10 (60%) as CAD-RADS 4, whereas conventional CT correctly classified 3 out of 8 (38%) stenoses as CAD-RADS 2, 4 out of 8 (50%) as CAD-RADS 3, and 5 out of 10 (20%) as CAD-RADS 4 (Supplemental Fig. 1, http://links.lww.com/RLI/A944). This corresponds to a total of 21 out of 26 (81%) stenoses correctly classified for SPCCT compared with only 11 out of 26 (42%) for conventional CT, using ICA as the gold standard.

SPCCT also led to 10 (38%) stenoses being reclassified, that is, stenoses that would have been wrongly classified with conventional CT, whereas only 1 (4%) was reclassified with conventional CT, that is, one that would have been wrongly classified with SPCCT (Fig. 3). Examples of cases representing reclassified stenoses are shown in Figures 4–6.

TABLE 3. ICC and Bland-Altman Agreements for ICA, SPCCT, and Conventional CT

Analysis	Parameter	Value	*P*
ICC	ICA and SPCCT	0.94 [0.86, 0.98]	<0.001
	ICA and conventional CT	0.65 [0.21, 0.84]	0.006
	SPCCT and conventional CT	0.69 [0.31, 0.86]	0.002
Bland-Altman agreement (%)	ICA and SPCCT	3 ± 7 [−10, 16]	<0.001
	ICA and conventional CT	0 ± 16 [−20, 30]	<0.001
	SPCCT and conventional CT	-1 ± 10 [−21, 20]	<0.001

Data are expressed as [95% CI] and means ± SD.
ICA, invasive coronary angiography; ICC, intraclass correlation coefficient.

Reader Agreement

Interreader ICC for stenosis measurements was excellent with SPCCT (ICC = 0.95 [95% CI, 0.82, 0.98], $P < 0.001$), as well as with conventional CT (ICC = 0.93 [95% CI, 0.86, 0.97], $P < 0.001$). Very good agreement (kappa = 0.89, $P < 0.001$) was found for SPCCT CAD-RADS categorization, whereas moderate agreement (kappa = 0.42, $P = 0.03$) was found for conventional CT. Subgroup kappa agreements separated into CAD-RADS categories, available in the Supplemental Results, http://links.lww.com/RLI/A946, confirmed the overall better agreement for SPCCT.

Diagnostic Performance

For the standard performance analysis, sensitivity, specificity, PPV, NPV, and accuracy were greater with SPCCT than with conventional CT for detecting >50% and >70% diameter stenoses (Fig. 3 and Table 4). For >50% stenoses, sensitivity was respectively, 100% versus 75%, specificity was 90% versus 50%, accuracy was 96% versus 65%, PPV was 94% versus 71%, and NPV was 100% versus 56%. For >70% stenoses, sensitivity was respectively 75% versus 37%, specificity was 100% versus 83%, accuracy was 92% versus 69%, PPV was 100% versus 50%, and NPV was 90% versus 75%.

For the intention-to-diagnose analysis, 25 noninterpretable segments were added (Table 5). The outcome was an increase in sensitivity and specificity for SPCCT, whereas it resulted in an increase in sensitivity and poorer specificity for conventional CT. The overall results were in favor of slightly better performance for SPCCT, with a slight increase in accuracy and a much better performance of conventional CT, with a significant increase in accuracy.

Significant differences ($P > 0.001$) for both 50% stenosis and 70% stenosis detection were found in the intention-to-diagnose analysis. For the standard analysis, the test showed nonsignificant differences for 50% stenosis ($P = 0.79$) and for 70% stenosis ($P = 0.21$) due to a small sample size.

AUCs were 0.95 and 0.63 for detecting >50% diameter stenoses and 0.88 and 0.60 for detecting >70% diameter stenoses with SPCCT and conventional CT, respectively, in the standard analysis, whereas they were 0.97 and 0.78 for detecting >50% diameter stenoses and 0.94 and 0.80 for detecting >70% diameter stenoses in the intention-to-diagnose analysis (Fig. 3). Results of individual measurements are available in Supplemental Tables 1–3, http://links.lww.com/RLI/A944, http://links.lww.com/RLI/A945, http://links.lww.com/RLI/A946.

SPCCT showed better performance compared with conventional CT for both low and high calcium score stenoses, but no statistical difference was found in the subgroup analysis available in Supplemental Table 4, http://links.lww.com/RLI/A946.

Radiation Dose Study

Mean tube current (257 mAs ± 98 vs 407 mAs ± 78, respectively; $P = 0.002$), mean volume CTDI (25.7 mGy ± 5.9 vs 34.9 mGy ± 5.7, $P = 0.013$), and mean dose-length-product (473 mGy ± 149 vs 719 ± 226, $P = 0.011$) were significantly lower with SPCCT. This corresponds to a CTDI reduction of 26% and a dose-length product reduction of 34% with SPCCT.

DISCUSSION

CCTA is an excellent imaging modality for the low-to-intermediate cardiovascular risk population.[25,26] However, its utility is controversial in high-to-very-high-risk patients due to impaired image quality. In the present study on a population with a recent history of acute coronary syndromes, we demonstrated that SPCCT outperforms conventional

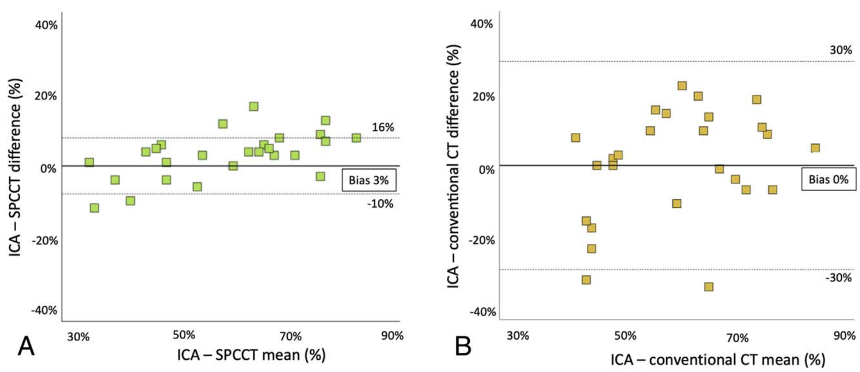

FIGURE 2. Bland-Altman analysis of agreement of percentage of stenosis. Spectral photon-counting CT (SPCCT) compared with invasive coronary angiography (ICA) (A) and conventional CT compared with ICA (B). 95% confidence intervals are displayed as dotted lines, and the solid line is the mean of the differences between the 2 techniques.

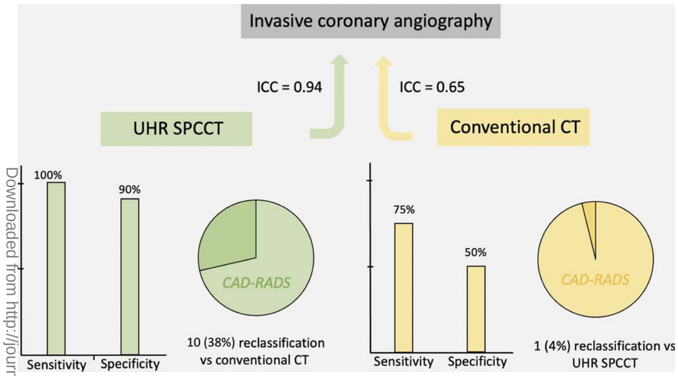

FIGURE 3. Overview of SPCCT and conventional CT performances versus ICA. Compared with conventional CT (in yellow), ultra-high-resolution (UHR) spectral photon-counting CT (SPCCT, in green) improves sensitivity and specificity for >50% diameter stenoses detection, using invasive coronary angiography (ICA) as the reference method. UHR SPCCT correctly reclassified 32% of stenoses that were misclassified with conventional CT, using CAD-RADS 2.0.

CT for quantifying significant coronary stenoses. Consequently, this leads to greater accuracy, specificity, and more CAD-RADS stenosis reclassification over conventional CT, using ICA as a reference. Noticeably, conventional CT alone performed worse than compared with previously published results, which we attribute to the high calcium score and very-high cardiovascular risk of our population. However, it is important to remember that few studies focus on very-high-risk patients, and thus have a tendency to include less atheromatous coronaries. Similarly, the CORE-64 study, which investigated a high-risk population, also observed a tendency toward poorer performance of conventional CT with increasing calcium burden.[27] However, the overall performance of conventional CT was still better than in this study, which we explain by the difference in the population risk, with an average calcium score of 148 versus 739 for this study. Indeed, scanning very high-risk patients poses greater challenges, including more unstable cardiac function leading to motion artifacts, reduced iodine contrast output, and more extensive disease with calcified and noncalcified lesions, which not only affect stenosis measurement but also the assessment of nonstenosed coronary sections required for stenosis diameter evaluation. This explains the absence of recommendations for this population subtype, whereas SPCCT could resolve such limitations.

UHR-CT coronary artery imaging is a promising means of improving the accuracy of stenosis quantification in CAD management. For example, Takagi et al[28] have shown excellent agreement with ICA with a range of 16% using a CT system equipped with an EID of 0.25 μm pixel size at the isocenter. This contrasts with studies using CT systems equipped with standard-sized EIDs, which only show good agreement with a wider range of limits (24%–28%).[29,30] However, the EIDs with which all these CT systems are equipped are limited by their intrinsic spatial resolution, dose efficiency, and absence of spectral capabilities, which would lead to a more comprehensive assessment of CAD and myocardial damage. SPCCT, however, is equipped with energy-resolving detectors, which, by definition, combine UHR capabilities and spectral imaging while benefiting from greater dose efficiency.[31,32] In this regard, many studies have highlighted

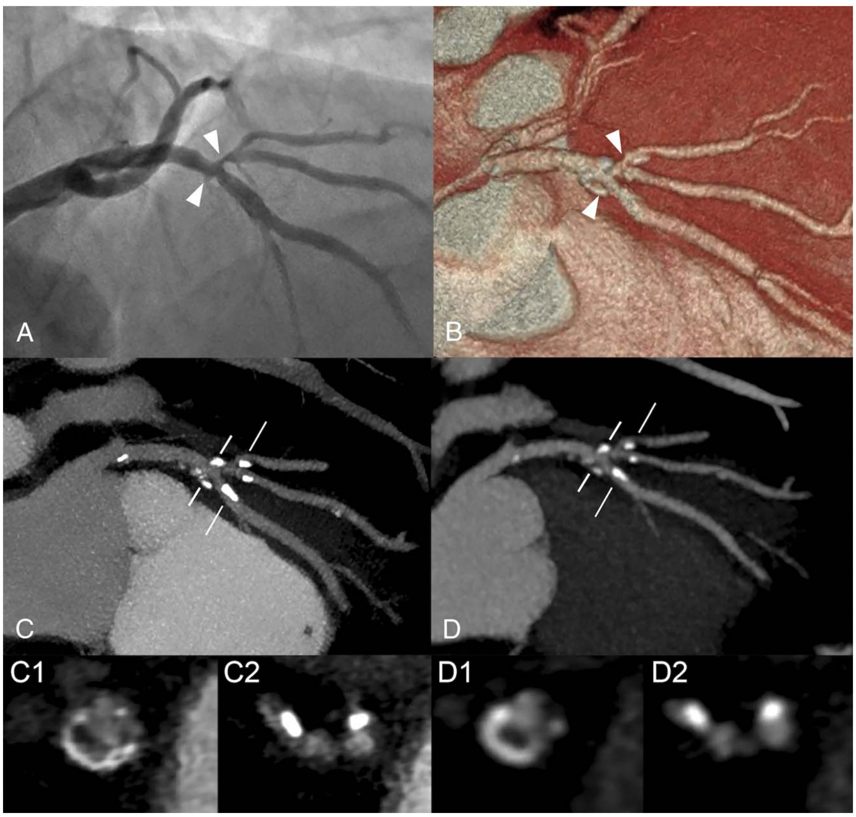

FIGURE 4. Coronary UHR SPCCT angiography imaging of a complex coronary stenosis. Example of 40% (CAD-RADS 2) complex stenosis (arrows) involving the proximal left anterior descending (LAD) artery and extending to neighboring diagonal branches, in a 66-year-old male. Invasive coronary angiography (ICA) (A), ultra-high-resolution (UHR) spectral photon-counting CT (SPCCT) (C), and conventional CT (D). Stenosis was evaluated as 42% (CAD-RADS 2) with SPCCT and 53% with conventional CT (CAD-RADS 3). Note the better plaque characterization with SPCCT compared with conventional CT, leading to a more accurate evaluation of coronary lumen and calcifications (C1 and C2).

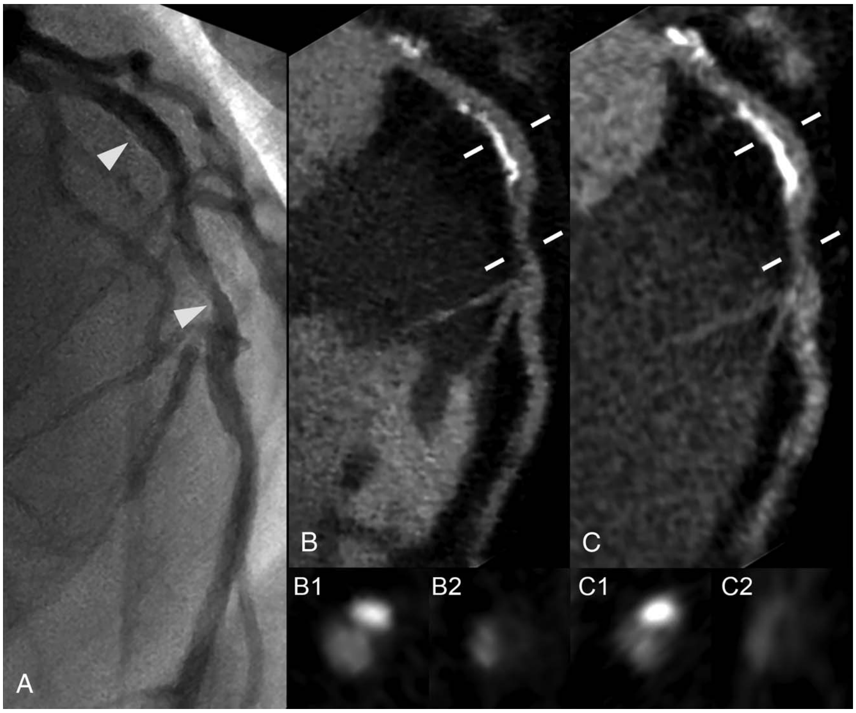

FIGURE 5. Coronary UHR SPCCT angiography of multiple consecutive coronary stenoses. Multiple consecutive mid-LAD stenoses (arrows) in a 58-year-old male. Invasive coronary angiography (ICA) (A). Ultra-high-resolution (UHR) spectral photon-counting CT (SPCCT) (B) and conventional CT (C) showed multiple calcified and noncalcified plaques. The most serious stenosis was evaluated as 52% (CAD-RADS 3) with ICA, 57% (CAD-RADS 3 with SPCCT), and 68% (CAD-RADS 3) with conventional CT. The entire segment was later treated by angioplasty and stenting.

the improved subjective quality of images with SPCCT. For example, Si-Mohamed et al[19] demonstrated 2 essential assets of SPCCT for CAD imaging. Indeed, compared with conventional CT, SPCCT improves the image quality of CAD hallmarks and boosts the diagnostic confidence of readers. In addition, previous studies have highlighted the improvements in image quality for stent imaging, recently in humans.[33] In the present study, in a head-to-head comparison between a SPCCT device and a conventional CT device from the same vendor, we confirm the expected benefits of UHR coronary artery imaging by showing a dramatic improvement in agreement with ICA, from good to excellent. We also found that the range of agreement improved by 56% using SPCCT, for a final range of 13%.

The present study also demonstrates a dramatic increase in the specificity of SPCCT, which is of great value in the very-high-risk population, as it may make it possible to rule out hemodynamically significant stenosis with great accuracy. Compared with conventional CT, the specificity increased from 50% to 90% for >50% diameter stenoses and from 83% to 100% for >70% diameter stenoses. These results align with those of Takagi et al,[28] who found a specificity of 96% for detecting stenoses >50% diameter. Similar results in a high-risk population were described in another study by Hagar et al,[34] who found 95% specificity for stenoses >50% diameter and 94% for stenoses >70% diameter using a SPCCT device from another vendor. Notably, the calcium score analysis revealed greater discrepancies between SPCCT and conventional CT performances for the high-calcium score patients, indicating that the benefits of SPCCT over conventional CT are particularly evident in this subgroup, where conventional CT performance declines. Those results corresponded to an AUC of 0.96 for >50% diameter stenoses, which is

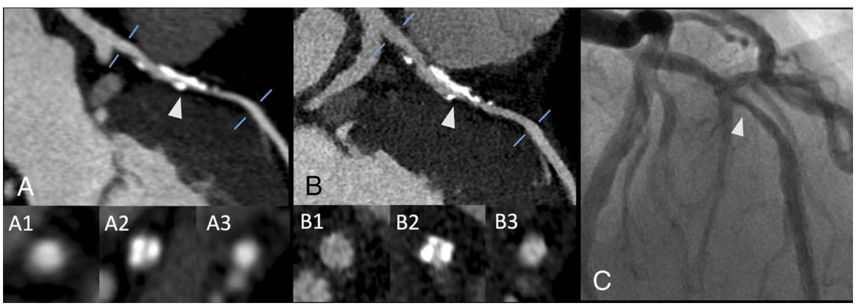

FIGURE 6. Coronary UHR SPCCT angiography imaging of a calcified LAD stenosis. Example of 50% (CAD-RADS 3) calcified stenosis (arrows) involving the proximal LAD in a 64-year-old female. Ultra-high-resolution (UHR) spectral photon-counting CT (SPCCT) (A), conventional CT (B), and invasive coronary angiography (ICA) (C). Stenosis was evaluated as 56% (CAD-RADS 3) with SPCCT and 72% (CAD-RADS 4a) with conventional CT. Note the reduced blooming artifacts with greater SPCCT resolution compared with conventional CT, leading to a more accurate evaluation of coronary lumen percentage stenosis.

TABLE 4. Diagnostic Performances of SPCCT and Conventional CT to Detect >50% and >70% Coronary Diameter Stenoses

	Coronary Stenoses >50%		Coronary Stenoses >70%	
	SPCCT	Conventional CT	SPCCT	Conventional CT
Sensitivity (%)	100 [79, 100]	75 [48, 93]	75 [35, 97]	37 [9, 75]
Specificity (%)	90 [55, 100]	50 [19, 81]	100 [81, 100]	83 [59, 96]
Accuracy (%)	96 [80, 100]	65 [44, 83]	92 [75, 99]	69 [48, 86]
PPV (%)	94 [71, 100]	71 [44, 90]	100 [54, 100]	50 [12, 89]
NPV (%)	100 [66, 100]	56 [21, 86]	90 [68, 99]	75 [51, 91]

Data expressed as [95% CI].

NPV, negative predictive value; PPV, positive predictive value.

similar to the AUC of 0.95 found in the present study. Altogether, they clearly illustrate the benefits of the detector's small pixel size with which these newly developed SPCCT systems are equipped.[31,35]

The intention-to-diagnose analysis shows that the rate of noninterpretable segments is possibly responsible of the lower performances for conventional CT, which is reflected by the very-high-risk profile of the population. For this subtype of population, SPCCT particularly shines as a superior modality to conventional CT. Indeed, its increased spatial resolution, reduced blooming artifacts, and finer lumen analysis are crucial for more accurate assessment of coronary stenosis in severely atheromatous segments.

Consequently, considering that CAD-RADS has become the recommended reporting system for CAD,[23] this present study shows that SPCCT is a better CAD-RADS categorizer than conventional CT. It leads to more stenosis reclassification versus EID-CT, as suggested in the study by Koons et al.[36] In their study, 38% of the total lesions included were downgraded in stenosis severity using scores based on CAD-RADS.[36] This is explained by a greater agreement between SPCCT and ICA than EID-CT and ICA, as also shown by Eberhard et al[37] who demonstrated a gain in Cohen's kappa coefficient (k 1/4 of 0.87 vs 0.77, respectively). These findings may be critical as they can completely change a patient's clinical pathway. It is also worth mentioning that a majority of stenoses (73%) were moderate-to-severe (CAD-RADS 3 or more), in other words above the 50% diameter stenosis significance threshold, which is essential as such values often indicate the need for further evaluation that may ultimately lead to stenosis treatment. However, although one might expect an overestimation of severe stenosis, we found that CAD-RADS 4 stenoses were underestimated with both CT systems. One possible explanation may be the difference in the reference diameters assessed on ICA and CT, with a tendency to underestimate the diameters using ICA due to an underestimation of the atherosclerotic wall burden. With CT, it is possible to assess plaque extension and may lead to upstream measurement of greater diameters than with ICA. Nonetheless, correct classification of severe stenosis was still greater than conventional CT.

Finally, this proof of evidence supports the comprehensive potential of SPCCT for the diagnosis of CAD, as well as functional assessment and treatment planning and execution, as suggested by recent studies.[20,26,37,38] Furthermore, the distinctive capabilities of this technology, enabling spectral imaging in combination with dedicated contrast agents, may offer opportunities for advancements in the evaluation of atherosclerotic burden.[39–42] Altogether, it may have the potential to be used systematically in the clinical workflow of high-to-very-high-risk cardiovascular patient management, as a diagnostic and treatment planning tool to help reduce procedure times and help choose the right stent and the right position for better outcomes.[43–45] Another potential advantage of SPCCT over conventional CT, not evaluated in this study, is its impact on noninvasive CT-derived fractional-flow reserve (FFR_{CT}),[46] as this is expected to be the future gold standard for coronary stenosis evaluation, taking into account the hemodynamic significance of vessel stenosis, ultimately affecting the treatment decision.

Study Limitations

Our study has several limitations. First, the number of very-high-risk patients included is fairly small. This is mainly due to the study's single-center design, with the limited capacity of a single SPCCT research platform, as well as a large number of patients without concomitant ICA. Second, we did not assess potential coronary stenoses detected on CT systems alone, as we used ICA as a gold standard. Finally, the clinical SPCCT system prototype has certain technical limitations such as a z-coverage of 1.76 cm, a rotation time of 0.33 seconds, absence of radiation dose modulation, and bolus tracking solutions. These factors, particularly the different rotation time, may have contributed to the large number of motion artifacts, and although the intention-to-diagnose analysis partially reduced this problem, it is not clear whether 1 of the 2 CT systems was advantaged or disadvantaged by it. However, these limitations are expected to be addressed in the near future, projecting further improvements to mitigate image quality and coronary motion artifacts.

TABLE 5. Intention-to-Diagnose Diagnostic Performances of SPCCT and Conventional CT to Detect >50% and >70% Coronary Diameter Stenoses

	Coronary Stenoses >50%		Coronary Stenoses >70%	
	SPCCT	Conventional CT	SPCCT	Conventional CT
Sensitivity (%)	100 [77, 100]	71 [42, 92]	95 [82, 99]	86 [71, 95]
Specificity (%)	97 [86, 100]	86 [71, 95]	100 [77, 100]	79 [49, 95]
Accuracy (%)	98 [90, 100]	82 [69, 92]	96 [87, 100]	84 [71, 93]
PPV (%)	93 [68, 100]	67 [33, 988]	100 [90, 100]	91 [77, 98]
NPV (%)	100 [90, 100]	89 [74, 97]	88 [62, 98]	69 [41, 89]

Data expressed as [95% CI].

NPV, negative predictive value; PPV, positive predictive value.

CONCLUSIONS

Ultra-high resolution coronary SPCCT angiography showed better correlation, sensitivity, specificity, and stenosis reclassification than conventional CT, using ICA as a reference.

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