International Journal of Cardiology 274 (2019) 382–387

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Diagnostic accuracy of coronary CT angiography performed in 100 consecutive patients with coronary stents using a whole-organ high-definition CT scanner

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ARTICLE INFO

Article history:
Received 6 June 2018
Received in revised form 31 July 2018
Accepted 3 September 2018
Available online 8 September 2018

ABSTRACT

Aims: To evaluate image quality, interpretability, diagnostic accuracy and radiation exposure of coronary CT angiography (CCTA) performed with a new scanner equipped with 0.23-mm spatial resolution, new generation iterative reconstruction, 0.28-second gantry rotation time and intra-cycle motion-correction algorithm in consecutive patients with coronary stents, including those with high heart rate (HR) and atrial fibrillation (AF).
Materials and methods: We enrolled 100 consecutive patients (85 males, mean age 65 ± 10 years) with previous coronary stent implantation scheduled for clinically indicated non-emergent invasive coronary angiography (ICA). Image quality, coronary interpretability and diagnostic accuracy vs. ICA were evaluated and the effective dose (ED) was recorded.
Results: Mean HR during the scan was 67 ± 13 bpm. Twenty-six patients had >65 bpm HR during scanning and 13 patients had AF. Overall, image quality was high (Likert = 3.2 ± 0.9). Stent interpretability was 95.8% (184/192 stents). Among 192 stented segments, CCTA correctly identified 22 out of 24 with >50% in-stent restenosis (ISR) (sensitivity 92%). In a stent-based analysis, specificity, positive and negative predictive values and diagnostic accuracy for ISR detection were 91%, 99%, 60% and 91%, respectively. In a patient-based analysis, CCTA diagnostic accuracy was 85%. Overall, mean ED of CCTA was 2.4 ± 1.2 mSv.
Conclusions: A whole-organ CT scanner was able to evaluate coronary stents with good diagnostic performance and low radiation exposure, also in presence of unfavorable HR and heart rhythm.
Translational aspect: The present study is the first to evaluate the CCTA capability of detecting in-stent restenosis in consecutive patients, including those with high HR and AF, using a recent scanner generation that combines improved spatial and temporal resolution with wide coverage. Using the whole-organ high-definition CT scanner we obtained high quality images of coronary stents with good interpretability and diagnostic accuracy combined with low radiation exposure, even in patients with unfavorable HR or heart rhythm for CCTA evaluation.

1. Introduction

Coronary CT angiography (CCTA) has emerged as a reliable tool for the diagnosis of coronary artery disease (CAD) and the evaluation of patients who underwent percutaneous coronary intervention (PCI) [1]. Although some studies showed reasonable diagnostic performance of 64-slice CCTA for in-stent restenosis (ISR) detection [2–6], a 9–10% rate of non-assessable stents has been reported by previous meta-analyses [7,8]. Moreover, previous CCTA studies enrolled selected patients with stable and low heart rate (HR) and excluded those with irregular heart rhythm or HR > 65 beats per minute (bpm) [9–11]. Thus, current appropriateness criteria still consider CCTA of questionable clinical value for coronary stent evaluation [12]. Recently, a new scanner has been introduced in the clinical field. The main technological innovations are improved spatial resolution (0.23-mm), a new-generation iterative reconstruction, faster gantry rotation time and an intra-cycle motion-correction algorithm enhancing temporal resolution [13]. Aim

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https://doi.org/10.1016/j.ijcard.2018.09.010

of the present study was to assess image quality and interpretability, diagnostic accuracy and radiation exposure of the new scanner in consecutive patients previously treated with coronary stents. They were enrolled irrespective of HR or presence of atrial fibrillation (AF), using invasive coronary angiography (ICA) as a reference standard.

2. Materials and methods

2.1. Study population

We prospectively assessed for enrollment 103 consecutive patients (85 men, mean age 65 ± 10 years). All patients were previously treated with coronary stent implantation and were scheduled for ICA between March 2015 and February 2016 because of anginal symptoms (n = 48, 47%) or positive stress test (n = 55, 53%). The mean time from index PCI to CCTA was 12 ± 7 months. Exclusion criteria were contraindications to contrast agent administration and impaired renal function (creatinine clearance <60 mL/min). Metoprolol was administered intravenously with a titration dose up to 25 mg to reduce HR. However, patients were enrolled regardless of HR at the time of scanning. We divided the population in two groups: patients with sinus rhythm and HR ≤65 bpm and patients with sinus rhythm and HR >65 bpm or with AF. Body mass index (BMI), prevalence of cardiovascular risk factors and serum creatinine were recorded. Written informed consent was obtained from all patients and the institutional ethics committee approved the study protocol.

2.2. Stent characteristics

Number and type of drug-eluting stent, number of bare-metal stent, stent material, stent size and number and type of complex stenting procedures were recorded.

2.3. Imaging protocol

We performed all CCTA with the same scanner (Revolution CT, GE Healthcare, Milwaukee, WI) using the following parameters: slice configuration 256 × 0.625 mm, gantry rotation time 280 ms and prospective ECG triggering. A BMI-adapted scanning protocol was used. We used a short X-ray window (100 ms) in the end-diastolic phase (i.e. 75% of the R-R cycle) in patients with sinus rhythm and HR ≤65 bpm and a wider X-ray window (500 ms) in the diastolic phases (i.e. 40–80% of R-R cycle) in those with sinus rhythm and HR >65 bpm or with AF. In all cases, a 50-mL (in ≤25 kg/m^2 BMI patients) or 60-mL (in >25 kg/m^2 BMI patients) bolus of contrast medium (Iomeron 400 mg/mL, Bracco, Milan, Italy) was administered through an antecubital vein at an infusion rate of 5 mL/s, followed by 50 mL of saline solution. Imaging was performed with the bolus-tracking (fluoroscopic-triggering) technique.

2.4. CCTA image reconstruction and analysis

Data sets of CCTA images were analyzed using a vessel analysis software (CardioQ3 Package-GE Healthcare, Milwaukee, WI). The 16 coronary segments classification of the American Heart Association was used [14]. Reconstructed images were independently evaluated by two readers (D.A. and S.M.) with over 10 years of clinical experience in CCTA performance and analysis who were blinded to clinical findings. In case of motion artifacts with standard reconstruction, we used an intra-cycle motion correction algorithm. Only the stented coronary segments were included in the analysis. A new generation iterative reconstruction (ASIR-V, GE Healthcare, Milwaukee, WI) and a stent-dedicated kernel (HD-detail) [11] were used for the reconstruction of coronary stent images. We used the 4-point Likert scale to assess image quality score. Each segment was scored as excellent (no artifacts, score = 4), good (minor artifacts, good diagnostic quality, score = 3), adequate (moderate artifacts, acceptable for routine clinical diagnosis, score = 2), or poor/non-evaluable/non-diagnostic (severe artifacts impairing accurate evaluation, segment classified as non-evaluable, score = 1) [15]. Image noise was defined as the standard deviation of CT density in a region of interest placed in the aortic root immediately cranial to the left main coronary artery. Attenuation within the lumen of the proximal coronary arteries was measured by placing the region of interest centrally in the left main, left anterior descending, left circumflex and right coronary arteries. To determine proximal vessel contrast enhancement, CT attenuation in the connective tissue was measured by placing the region of interest immediately next to the vessel contour and subsequently determining the difference in CT attenuation between the vessel lumen and surrounding tissue. The signal-to-noise ratio (SNR) was determined dividing mean attenuation by image noise. The contrast-to-noise ratio (CNR) was determined dividing contrast value by image noise. Using transverse source images and multi-planar reconstructions, stented segments and native coronary segments were evaluated for the presence of significant ISR or de novo stenosis, defined as a narrowing of the coronary lumen exceeding 50% [16,17]. Consensus agreement was achieved for any disagreement in data analysis between the two readers.

2.5. Invasive coronary angiography

Conventional coronary angiography was performed with a standard technique. Two experienced operators (A.B. and P.M.) with over 20 years of clinical experience in ICA who were blinded to CCTA findings evaluated the stented and peri-stent segments (5 mm proximal and distal to the stent edges) using the “sharpest and tightest” view of the target lesion free of foreshortening or vessel overlap. Analysis of angiograms was performed with an automated edge-contour quantitative coronary angiography system (QuantCor QCA, Pie Medical Imaging, Maastricht, The Netherlands). Binary ISR was defined as a diameter stenosis ≥50%.

2.6. Radiation dose parameters

The effective dose (ED) of CCTA was calculated according to the European Working Group for Guidelines on Quality Criteria in CT [18] (dose-length product [DLP], defined as total radiation energy absorbed by patient body times a conversion coefficient for the chest [K = 0.014 mSv/mGy ∗ cm]). For ICA, we calculated ED by multiplying the dose-area product (DAP) by a conversion factor (DAP to ED = 0.2 mSv/Gcm^2) for lateral and posterior-anterior radiation exposure in the chest area [19].

2.7. End points of the study

The primary end points of the study were the rate of CCTA evaluability in a stented-based analysis, the CCTA diagnostic accuracy in a stented-based analysis and the ED of CCTA.

2.8. Statistical analysis

Statistical analysis was performed using the SPSS 22.0 software (SPSS Inc., Chicago, IL). A power calculation on adequacy of sample size was performed. Assuming an ISR prevalence of 10%, at least 170 stent segments were needed to detect sensitivity and specificity with a 95% confidence interval. We supposed that sensitivity and specificity were at least 90%. The D'Agostino-Pearson test was used for testing normal and non-normal distribution. Continuous variables were expressed as mean ± SD or as median (interquartile range), as appropriate, while discrete variables as absolute numbers and percentages. The Student's *t*-test or Mann-Whitney test were used to test differences in continuous variables, as appropriate. The Chi-squared test or Fisher's exact test were used to study differences regarding categorical data. The CCTA evaluability, sensitivity, specificity, negative predictive value, positive predictive value and accuracy were calculated vs. ICA in a stent-based analysis using stent classified as evaluable and including all stents for analysis, with non-evaluable stents censored as “positive”. Moreover, the CCTA diagnostic accuracy vs. ICA was calculated in a patient-based analysis considering a patient as “positive” in the presence of at least one ISR and/or one >50% stenosis in the native coronary segments. The diagnostic performance of CCTA between the two groups was compared using the pairwise McNemar's test. The intra-observer and inter-observer variability for the detection of significant ISR (defined as any stenosis >50% and considered as a dichotomy variable) in CCTA and ICA images was tested with Cohen's Kappa. This analysis was performed on a per-stent level and every single coronary stent was considered as an independent variable. ICA was considered as the gold standard for comparison with CCTA and a consensus agreement between the two readers was considered as the gold standard for analysis of ICA inter-observer and intra-observer variability. The interval between repeat analyses for intra-observer variability assessment was at least 1 week. Moreover, univariate and a multivariate analyses were performed to assess the effects of HR during the scan, stent diameter, stent strut thickness and stent material on the evaluability of CCTA.

3. Results

3.1. Baseline characteristics

Table 1 shows the clinical and procedural characteristics of the study population. We excluded three patients because of impaired renal function. Among 100 enrolled patients, 61 were in sinus rhythm with HR ≤65 bpm, whereas 26 were in sinus rhythm with HR >65 bpm and 13 had AF.

3.2. CT evaluability and image quality

The Supplementary Table 1 shows the image quality score using the 4-point Likert scale in the entire population and in the two groups of patients. Overall image quality was high (Likert = 3.16 ± 0.9). No significant difference was found in the image quality score between patients with low HR and those with high HR or AF (Likert = 3.23 ± 0.8 vs. 3 ± 0.9, p = 0.09). Sixteen stents were classified as non-evaluable/non-interpretable after standard reconstruction. In eight cases, this was due to beam-hardening artifacts occurring in stents with a <3-mm diameter. In the remaining eight cases, motion artifacts were the cause of non-evaluability. We processed the latter eight cases with additional reconstruction using the intra-cycle motion-correction algorithm. With this technique we reclassified image quality of the 8 non-evaluable stents as follows: adequate (Likert 2) in 3 cases, good (Likert 3) in 3 cases and excellent (Likert 4) in 2 cases. Therefore, the algorithm increased stent

Table 1
Clinical and procedural characteristics of study patients.

Number of patients enrolled	100
Patients with sinus rhythm, HR ≤ 65 bpm	61
Patients with sinus rhythm, HR > 65 bpm	26
Patients with atrial fibrillation	13
Age, (years)[a]	67 (64–68)
Male/female	85/15
Mean time from index PCI to CCTA, months	12 (8–14)
Mean time from CCTA and clinically-indicated ICA, days	7 (4–8)
BMI[a]	25 (23–27)
Hypertension (≥140/90 mm Hg)	49
Hypercholesterolaemia (>200 mg/dL)	60
Diabetes mellitus	14
Current smoking	15
Family history of CAD	55
Serum creatinine(mg/dL)[a]	1 ± 0.2
HR before metoprol:	
HR in patients with sinus rhythm, HR ≤ 65 bpm[a]	63 (54–69)
HR in patients with sinus rhythm, HR > 65 bpm[a]	80 (73–88)
HR in patients with atrial fibrillation[a]	85 ± 11
Metoprolol	
Acute (intravenous)	53
Chronic (oral administration)	26
Average dose (mg)	
Acute[a]	11 ± 9
Chronic[a]	72 ± 16
HR after metoprolol:	
Mean HR during imaging in the entire population (bpm)[a]	67 (53–80)
HR in patients with sinus rhythm, HR ≤ 65[a]	57 (50–63)
HR in patients with sinus rhythm, HR > 65[a]	73 (60–89)
HR in patients with atrial fibrillation[a]	85 ± 11
Stent number	192
Stents per patient[a]	1.9
Drug-eluting stent	170
Paclitaxel-eluting stent	40 (21%)
Sirolimus-eluting stent	60 (31%)
Everolimus-eluting stent	70 (36%)
Bare-metal stent	22 (13%)
Stent material	
Stainless	101 (53%)
Cobalt-chromium	91 (47%)
Stent size	
Nominal stent diameter (mm)[a]	3.12 ± 0.55
Diameter <3.0	72 (37%)
2.75 mm	52
2.5 mm	18
2.25 mm	2
Diameter ≥3.0	120 (63%)
4.0 mm	12
3.5 mm	56
3.0 mm	52
Post-dilation	130 (68%)
Complex bifurcation stenting,	21 (11%)
T-stenting	16 (76%)
V-stenting	5 (24%)

CAD: coronary artery disease; HR; heart rate.
[a] Data are expressed as mean ± standard deviation or median (interquartile range) as appropriate.

interpretability to 95.8% (184 out of 192 stents evaluable), without significant differences between the 2 groups (121/125 evaluable stents [96.8%] in low HR patients vs. 63/67 evaluable stents [94%, p = 0.3] in high HR or AF patients, respectively). Table 3 reports the analysis of stent evaluability in relation to stent diameter, strut thickness and stent material. The only univariate predictor of stent segment non evaluability due to poor image quality was a stent diameter <3.0 mm (odd ratio 12.515, CI 95% 1.51–103.94, p = 0.003). The Supplementary Table 2 reports the quantitative image quality, including contrast density, CNR and SNR assessment.

3.3. Diagnostic accuracy of CCTA

Table 4 reports the diagnostic accuracy parameters of CCTA vs. ICA for the detection of >50% ISR in a stent-based analysis. Among 184 stent segments classified as evaluable, CCTA correctly identified >50% narrowing in 22 of the 24 stents showing ISR at ICA (sensitivity 92%). All stents with total occlusion (n = 6) were correctly identified by CCTA. Table 3 reports the diagnostic accuracy based on differences in stent diameter, strut thickness and stent material. Table 2 shows the diagnostic accuracy parameters of CCTA vs. ICA in a stent-based analysis in patients with stable and low HR and in those with high HR or AF. No significant differences were found in any parameter between groups. The Kappa value for the detection of significant ISR by CCTA was 0.91 for intra-observer agreement and 0.88 for inter-observer agreement. The Kappa value for the detection of significant ISR by ICA was 0.95 for intra-observer agreement and 0.89 for inter-observer agreement. The Supplementary Table 3 shows the diagnostic accuracy parameters of CCTA vs. ICA in a patient-based analysis in the two groups of patients and in the entire population. The CCTA diagnostic accuracy was 85.2% in patients with stable and low HR, 84.6% in those with high HR or AF and 85% in the entire population, respectively.

3.4. Radiation dose parameters

The average DLP of CCTA was 171.4 ± 85.6 mGy·cm, with mean values of 114.3 ± 100 mGy.cm and 235.7 ± 92.8 mGy·cm in the group with HR ≤65 bpm and in that with HR >65 bpm or AF, respectively. The mean ED was 2.4 ± 1.2 mSv in the overall population, 1.6 ± 1.4 mSv in patients with HR <65 bpm and 3.3 ± 1.3 mSv in those with high HR or AF. The average ED of CCTA was significantly lower than that of ICA (2.4 ± 1.2 mSv vs. 7.1 ± 1.6 mSv, p < 0.001).

4. Discussion

The present study is the first to evaluate the CCTA capability of detecting ISR in a cohort of consecutive patients, including those with high HR or AF, using a recent scanner generation that combines improved spatial and temporal resolution with wide coverage. The main finding of our

Table 2
Comparison in a stent-based analysis of the diagnostic accuracy of CCTA versus ICA for the detection of significant (>50%) in-stent restenosis in patients with HR ≤65 bpm and in patients with HR >65 bpm or AF.

	N	TN	TP	FN	FP	Sn (95% CI)	Sp (95% CI)	NPV (95% CI)	PPV (95% CI)	Accuracy (95% CI)
HR ≤65										
Stent-based analysis (using evaluable stents only)	122	98	13	1	10	92.9 (66.1–99.8)	90.7 (83.6–95.5)	99 (94.5–99.9)	56.5 (34.5–76.8)	90.1 (83.3–94.8)
Stent-based analysis (using all stents, with non-evaluable stents censored as positive)	125	97	15	1	12	93.7 (69.8–99.8)	90 (81.6–94.2)	99 (94.5–99.9)	55.6 (35.3–74.5)	89.6 (82.9–94.3)
HR >65 or AF										
Stent-based analysis (using evaluable stents only)	62	47	9	1	5	90 (55.5–99.7)	90.4 (78.9–96.8)	97.9 (88.9–99.9)	64.3 (35.1–87.2)	90.3 (80–96.4)
Stent-based analysis (using all stents, with non-evaluable stents censored as positive)	67	48	9	1	9	90 (55.5–99.7)	84.2 (72.1–92.5)	98 (89.1–99.9)	50 (26–73.9)	85.1 (74.3–92.6)

FN: false negative; FP: false positive; NPV: negative predictive value; PPV: positive predictive value; Sn: sensitivity; Sp: specificity; TN: true negative; TP: true positive.

Table 3
Evaluability and diagnostic accuracy of CCTA in relation to stent characteristics during imaging, using only evaluable stents for analysis.

Stent characteristics	N	Evaluability (%)	TP	TN	FP	FN	Sn (%)	Sp (%)	PPV (%)	NPV (%)	Accuracy (%)
Stent diameter (mm)											
<3.0	72	91.6 (82.6–96.8)	10	45	11	1	90.1 (58.7–99.7)	80.3 (67.6–89.7)	47.6 (27.7–70.2)	97.8 (88.5–99.9)	82.1 (71.3–90.1)
≥3.0	120	96.8 (91,9–99.2)*	12	100	4	1	92.3 (63.9–99.8)	96.1 (90.4–98.9)*	75 (47.6–99.9)	99.1 (94.6–99.9)	95.7 (90.3–98-6)*
Strut thickness (μm)											
<100	92	96.7 (90.7–99.3)	14	68	7	1	93.3 (68.1–99.8)	90.7 (81.7–96.2)	66.7 (43.1–85.4	98.6 (92.2–99.9)	91.1 (83.3–96.1)
≥100	100	95 (88.7–98.4)	8	77	8	1	88.9 (51.7–99.7)	90.6 (82.3–95.8)	50 (24.65–75.3)	98.7 (93.1–99.9)	90.4 (82.9–95.4)
Stent material											
Stainless steel	101	96 (90.1–98.9)	9	76	12	2	81.8 (48.2–97.7)	86.4 (77.4–92.7)	42.8 (21.8–65.9)	97.4 (91.1–99.7)	85.8 (77.4–91.5)
Cobalt-chromium	91	95.6 (89,1–98.8)	13	69	3	0	100 (75.3–100)	95.8 (88.3–99.1)¥	81.2 (54.3–95.9)¥	100 (94.8–100)	95.5 (88.9–98.7)¥
Stented vessel											
LMCA	11	100 (71.5–100)	2	9	0	0	100 (15.8–100)	100 (66.4–100)	100 (15.81–100)	100 (66.4–100)	100 (71.5–100)
LAD	87	96.6 (90.3–99.3)	8	68	6	0	100 (63.1–100)	91.9 (83.2–96.9)	57.1 (28.8–82.3)	100 (94.7–100)	92.7 (85.1–97.2)
LCX	53	96.6 (87.6–99.7)	6	37	4	1	85.7 (42.1–99.7)	90.2 (76.9–97.3)	60 (26.3–87.8)	97.4 (86.2–99.9)	89.6 (78.2–96.3)
RCA	41	95.1 (83.4–99.4)	6	31	5	1	85.7 (42.1–99.7)	86.1 (70.5–95.3)	54.5 (23.4–83.3)	96.9 (83.8–99.9)	86.1 (71.7–94.9)

FN: false negative; FP: false positive; LAD: left anterior descending artery; LCX: left circumflex artery; LMCA: left main coronary artery; NPV: negative predictive value; PPV: positive predictive value; RCA: right coronary artery; Sn: sensitivity; Sp: specificity; TN: true negative; TP: true positive.
* $p < 0.05$ stent diameter <3.0 mm vs. ≥3.0 mm.
¥ $p < 0.05$ stainless steel vs. cobalt chromium.

study is that the novel whole-organ high-definition CT scanner provided high quality images of coronary stents, allowing good interpretability and diagnostic accuracy combined with low radiation exposure. Of note, this was achieved despite a sizable number of patients had unfavorable HR or heart rhythm for CCTA evaluation (Figs. 1 and 2). At the patient-level, the diagnostic accuracy of CCTA was still good but lower than that observed in the stent-based analysis. With regard to image quality, the average value of Likert scale was high, owing to the fact that most stent images were of excellent quality (45%) or good quality with minor artifacts only (30%) in the entire population. The elimination of severe motion artifacts with the intra-cycle motion-correction algorithm may explain the low rate of non-evaluable stents. Previous studies demonstrated that this technique is an effective method per se for improving image quality and diagnostic accuracy of CCTA in patients with high HR or heart rhythm variability [15,20]. Concerning CCTA diagnostic accuracy vs. ICA for >50% ISR detection, the non-invasive imaging modality was able to correctly identify 22 out of 24 stented coronary segments showing >50% ISR at ICA. This indicates a sensitivity of 92% in a stent-based analysis. Moreover, the very high negative predictive value (99%) for stent assessment supports the concept that CCTA may be the gatekeeper for ICA, at least in the subset of previously stented patients without a high atherosclerotic burden in the non-stented coronary tree. Indeed, in the patient-based model, in which >50% stenoses in the non-stented coronary segments were included in the analysis, the diagnostic accuracy of CCTA decreased to approximately 85% in the two groups of patients and in the entire population. Moreover, although we found high sensitivity and diagnostic accuracy, the low positive predictive value may indicate the need of further downstream tests before sending asymptomatic patients to ICA in case they have a positive CCTA finding. Interestingly, the current literature, including CCTA guidelines and meta-analysis, suggests using CCTA for ISR detection only in patients who underwent PCI of the proximal coronary segments allowing the use of stents with a diameter ≥3.0 mm. This is due to the low interpretability and diagnostic accuracy of smaller coronary stents. Our study confirms the trend of better diagnostic performance in the bigger stents. Indeed, interpretability and diagnostic accuracy were 96.8% and 95.7% for stents with a diameter ≥3.0 mm. However, we found good interpretability (91.6%) and acceptable diagnostic accuracy (82.1%) also in patients with <3.0-mm diameter stents. This is likely the result of using a scanner with improved spatial resolution (0.23 mm) that is also able of scanning patients in a single cardiac beat. The latter technical feature may significantly decrease motion artifacts that are known to enhance beam-hardening effects generated by metallic stent strut. It is noteworthy that the good diagnostic performance of the new scanner was associated with low radiation exposure in the overall population (2.4 ± 1.2 mSv), in patients with HR <65 bpm (1.6 ± 1.4 mSv) and in those with high HR or AF (3.3 ± 1.3 mSv). Indeed, the

Table 4
Diagnostic accuracy in a stent-based analysis of CCTA for the detection of significant (>50%) in-stent restenosis in the overall population.

All population	N	TN	TP	FN	FP	Sn (95% CI)	Sp (95% CI)	NPV (95% CI)	PPV (95% CI)	Accuracy (95% CI)
Stent-based analysis (using evaluable stents only)	184	145	22	2	15	91.7 (73–98.9)	90.6 (85–94.7)	98.6 (95.2–99.8)	59.5 (42.1–75.3)	90.7 (85.5–94.5)
Stent-based analysis (using all stents, with not evaluable stents censored as positive)	192	145	24	2	21	92.3 (74.9–99.1)	87.3 (81.3–92)	98.6 (95.2–99.8)	53.3 (37.9–68.3)	88 (82.5–92.2)

FN: false negative; FP: false positive; NPV: negative predictive value; PPV: positive predictive value; Sn: sensitivity; Sp: specificity; TN: true negative; TP: true positive.

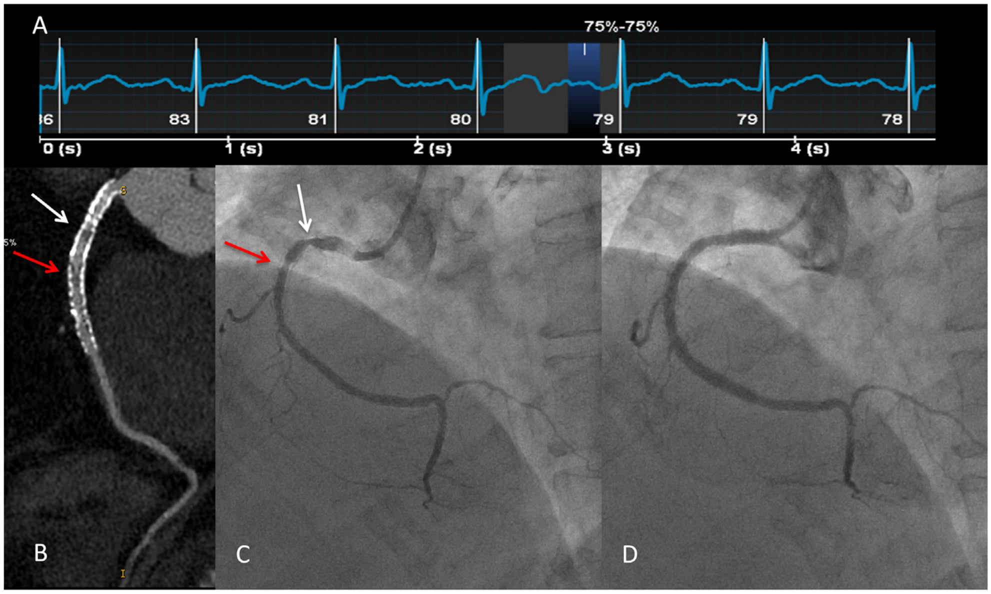

Fig. 1. Detection of severe ISR by CCTA that was confirmed by ICA in a patient with high heart rate. Despite the acquisition was performed at a HR of 79 bpm (panel A), CCTA was able to identify two sites of significant narrowing of a stent implanted in the right coronary artery (panel B, arrows). The CCTA finding was confirmed by ICA (panel C, arrows) and ISR was treated with a drug-eluting balloon with a good angiographic result (panel D).

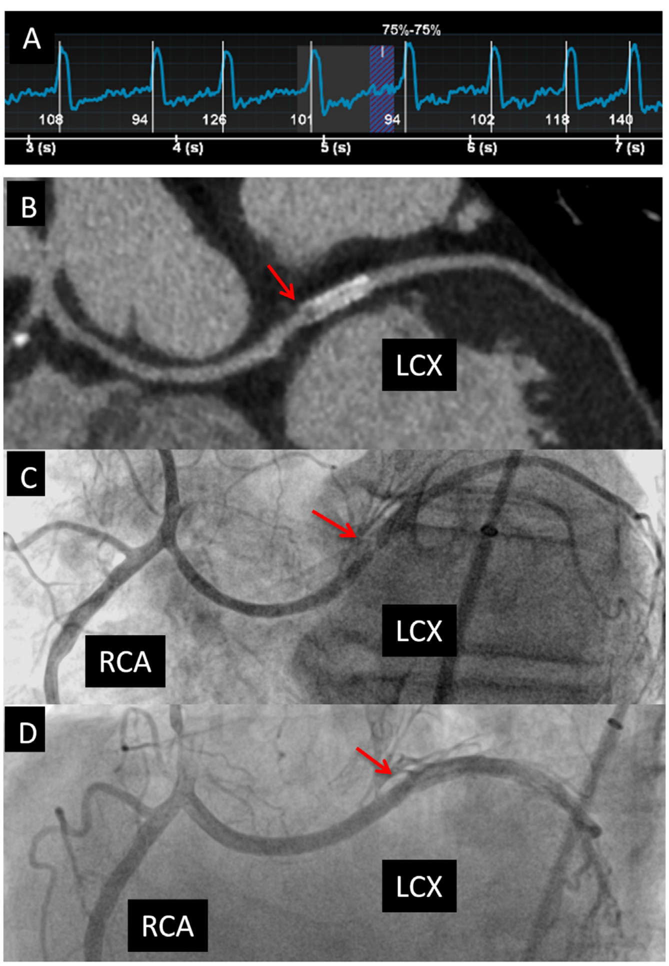

Fig. 2. Detection of severe ISR by CCTA that was confirmed by ICA in a patient with atrial fibrillation and high heart rate. Despite atrial fibrillation and a heart rate of 94 bpm during the scan (panel A), CCTA was able to detect subocclusion of a stent implanted in the left circumflex coronary artery that showed anomalous origin from the right coronary artery (panel B, arrow). The severe ISR was confirmed by ICA (panel C, arrow) and was successfully treated with drug-eluting stent implantation (panel D, arrow).

literature reports significantly higher values of radiation exposure (>10 mSv in most studies) in these clinical conditions, even when recent scanner generations were used [21,22]. Moreover, in our study intravenous metoprolol before scanning reduced HR in AF patients. This avoided double-scan acquisition, a technique previously suggested for AF patients undergoing CCTA [23], further decreasing radiation exposure.

4.1. Study limitations

Some limitations of this study should be acknowledged. First, stents with very small diameter were under-represented in our study. Indeed, despite 70 out of the 192 analyzed stent segments had a diameter <3 mm, the overall mean diameter of stents was 3.12 mm. Moreover, among stents with a diameter <3.0 mm, almost all had a diameter of 2.75 mm. Second, the number of patients with high and irregular HR was small (39 cases) and the mean HR in AF patients was relatively low (73 bpm). Thus, additional larger studies are needed in patients with irregular HR. Finally, ICA showed ISR in 24% of patients only. We recognize that the diagnostic accuracy of CCTA may have been overestimated in our patients who had low rate of ISR as compared to other populations (i.e., patients with a different rate of positive stress tests) with higher incidence of ISR. Finally, the present study was focused on the diagnostic accuracy of a new scanner generation for ISR detection. Accordingly, no data on patient follow-up and clinical outcomes are available. Further studies are needed to know the prognostic role of CCTA in the clinical setting of stented patients.

5. Conclusions

The scanner used in the present study was able to evaluate coronary stent patency with high image quality and diagnostic accuracy in patients with suspected ISR, even in those with unfavorable HR or heart rhythm. At the patient-level, the CCTA diagnostic accuracy was good but lower if compared with the stent-related findings.

Conflict of interest

The authors assure that no relationship with industry and no competing interests exist.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2018.09.010.

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