Evaluation of Low-kVp Low-Volume Iodinated Contrast Protocol for Coronary CT Angiography Using Retrospective ECG Gating

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Abstract

Objective The aim of this study was to evaluate the use of low peak kilovoltage (kVp) low-volume iodinated contrast protocol for performing coronary computed tomography (CT) angiography (CCTA) in patients using retrospective electrocardiogram (ECG) gating.

Materials and Methods Hundred prospective patients undergoing CCTA were studied in two groups, A and B, using 70 kilovoltage (kV) and 120 kV protocols with half and standard intravenous volumes of injected iodinated contrast, respectively. All patients had heart rates less than 100 beats/min and body mass index (BMI) less than 31 kg/m^2. Both the groups were evaluated for signal-to-noise (S/N) and contrast-to-noise (C/N) ratios along with radiation dose delivered in millisievert (mSv), and for image quality (IQ), on per patient and per segment basis.

Results Patients with group A showed statistically reduced radiation dose of 1.86 mSv compared with 6.86 mSv in group B patients. Marked reduction in image noise with statistically improved S/N and C/N ratios in all coronary vessels was seen in group A. S/N ratios in group A were 20.25, 18.68, 19.04, 17.41, and 18.69 for aorta, left main, left anterior descending, right coronary, and left circumflex arteries while they were 13.34, 11.12, 10.96, 9.74, and 8.67 in group B patients. C/N ratios were also higher in all vessels in group A patients, that is, 19.48, 19.48, 19.04, 19.48, and 17.68, compared with group B patients, who had 12.43, 10.03, 9.23, 9.57, and 8.23 ratios ($p < 0.0001$). No significant difference in IQ per patient and per vessel was seen between both the groups.

Discussion Retrospective ECG-gated low-kVp low-volume iodinated contrast protocol provides good diagnostic quality angiograms in patients with BMI up to 31 kg/m^2 and with heart rates of less than 100 beats/min with three times reduced radiation dose. The reduced volume of contrast reduces the cost as well as the chance of contrast-induced nephropathy.

Keywords
- coronary CT angiography
- low kVp
- radiation

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Introduction

It is appropriate to use coronary computed tomography (CT) angiography (CCTA) not only to screen patients for coronary artery disease but also in the setting of acute chest pain, especially when echocardiography and electrocardiogram (ECG) results are divergent.[1] However, the use of standard 64 slice CCTA carries a potential hazard of high radiation that varies from 6 millisievert (mSv) to 15 mSv, even with the use of dose reduction techniques.[2] There are also concerns related to contrast-induced nephropathy after performing coronary angiography and whether these could be mitigated by reducing the volume injected.[3,4] A variety of dose-reduction methods like reducing tube voltage, iterative reconstruction, and high-pitch modes are being used.[5,6] Prior studies done using only low kilovoltage (kV) techniques with prospective ECG gating on patients with body mass index (BMI) less than 25 kg/m^2 and with controlled heart rates less than 60 beats/min have shown that 30 to 80% dose reduction is possible to as low as 0.2 mSv but with increased image noise and reduced image quality (IQ),[7] which have been corrected with the use of newer iterative reconstruction techniques.[8] Obesity is prevalent worldwide and is a comorbid factor in coronary artery disease, and clinical imaging involves doing examinations on a large number of obese patients who have BMI >25 kg/m^2. Another challenge in performing coronary CT has been the issue of high heart rate, that is, more than 70 beats/min; hence, choosing a prospective gating technique on single slice scanners may not be possible all the time, therefore spiral retrospective ECG gating protocols are selected. To our knowledge, no retrospective gating technique has been evaluated to determine if low-dose low-volume protocol can be useful to examine such patients.

This study was designed to evaluate if low-kV and low-volume scan with retrospective ECG-gated protocol can be done to perform CCTA of such patients with BMI up to 31 kg/m^2 and or with higher heart rates up to 100 beats/min when compared with standard 120 kV angiographic protocol.

Materials and Methods

This was a randomized study comprising of 100 prospective patients who visited our institute for CCTA. Approval was taken by local ethical committee of the institute. The patients were randomized into two groups of 50 patients each. First group (A) underwent angiographic examination using a protocol with 70 kV tube voltage and 35 mL noniodinated intravenous contrast iomeron 400. The second group (B) had angiographic examination done using standard protocol of 120 kV tube voltage and 90 mL of same noniodinated contrast.

The demographic parameters of all patients, that is, age, sex, BMI, along with history of disease, coexisting morbidities like hypertension, diabetes, and hyperlipidemias, were recorded. All patients with history of allergy to iodine, arrhythmias, heart rate of more than 100 beats/min, BMI more than 31 kg/m^2, increased creatinine levels >1.2 mg/mL, or any prior bypass grafting/angioplasty were excluded.

All patients underwent CT examination after obtaining informed consent on dual energy CT system (Siemens Go-Top) 128 slice scanner after receiving oral 50 mg metoprolol 1 hour before the examination. Tube voltage was set according to the group of patients being examined using the protocol described. A retrospectively gated ECG-triggered spiral (pitch 0.3) acquisition was done with collimation and gantry rotation time of 0.31 milliseconds in both the groups. For group A patients, the tube voltage was fixed at 70 kV along with automated tube current modulation using CARE Dose 4D (Siemens healthineers), and the quality reference voltage and current was set to 120 kV and 320 milliampere-seconds (mAs). R-R interval was fixed at 35 to 75%. Also, 35 mL of noniodinated contrast iomeron 400 (Iomeprol 400 mg iodine/mL; Iomeron Bracco UK Ltd) was injected using bolus tracking software with dual head injector (Medrad, Stellant, Bayers, Munich, Germany) with flow rate of 4 mL/s followed by 20 mL saline. Image reconstruction was done using sinogram-affirmed iterative reconstruction (SAFIRE; Siemens healthineers level 3) with reconstruction kernel of BV36. For group B patients, according to the protocol the tube voltage was fixed at 120 kV with 90 mL of iomperal 400 injected intravenously at flow rate of 5 mL/s using bolus tracking as in group A followed by 40 mL saline. All images were transferred to Siemens Syngo.via workstation for postprocessing in multiplanar and volume rendering projections.

Radiation dose was calculated in both groups of patients by the system and displayed in the form of dose-length product, which was converted to mSv using conversion factor of 0.014.

Image Evaluation

Contrast attenuation values of ascending aorta (AAO), left main coronary, proximal right coronary artery, proximal left anterior descending, and left circumflex arteries were obtained by drawing region of interest within the lumen of respective vessels and value deemed as signal of the vessel. The standard deviation of the above displayed in the region of interest was the noise value and quotient of the two obtained was signal-to-noise (S/N) ratio. Contrast-to-noise (C/N) ratio was determined by attenuation value of vessel minus attenuation value of adipose tissue/attenuation value of noise of vessel.

IQ was rated on a score of 1 to 4 with score 4 as excellent, 3 as moderate but acceptable, 2 as average, and 1 as being poor and rejected by all the three authors independently. All scores were determined on per patient and per vessel basis.

Statistical Analysis

Statistical analysis was done using Analyze-IT software (Leeds, UK). Mean values with standard deviations were obtained of all categorical variables and Student's *t*-test done to determine the difference in significance. Mann-Whitney U test was done for categorical variables. Post hoc power analysis was done for the study and power fixed at 0.78 for both groups with significance level being fixed at $p = 0.05$. Interobserver agreement (IOA) was calculated using Kappa variable for IQ. Kappa of more than 0.6 was labeled as good agreement.

Table 1 Patient demographics

	GROUP A			GROUP B			p Value
SEX	32M/18F			35M/15F			0.1
AGE	57.0 Years	54.8	to 59.2	57.2Years	55.1	to 59.4	0.8
BMI	30.16	29.69	to 30.62	30.49	30.09	to 30.88	0.56
Heart Rate	72 bts/mt	64-85		74 bts/mt	68-86		0.45
Diabetes	18			16			0.67
Hypertension	33			35			0.56
Dyslipidemia	28			24			0.4

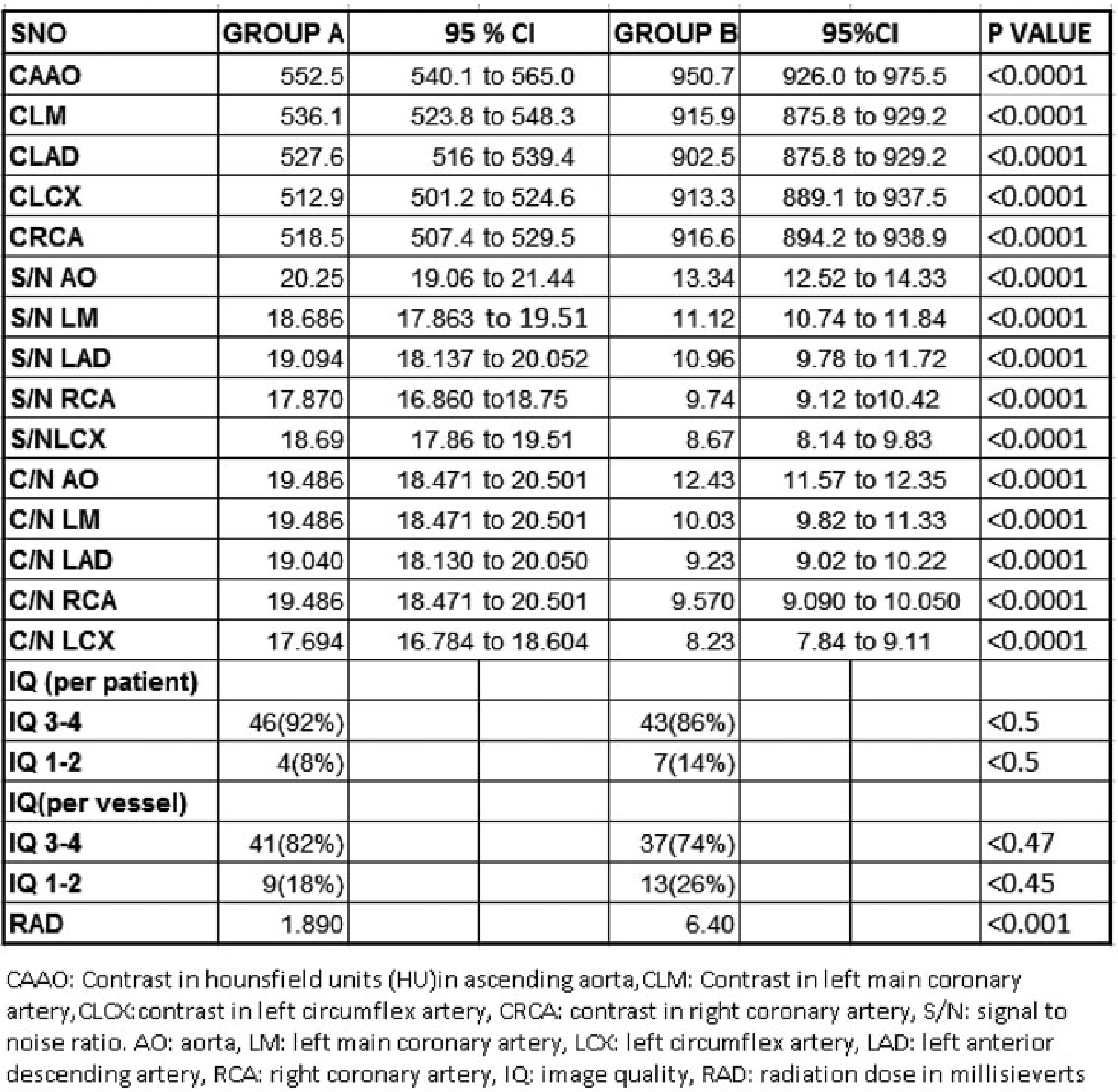
Results

Patient demographics of both groups are shown in ►**Table 1**. The mean age in both the groups was 57 and 57.2 years with mean BMI of 30.16 and 30.49 kg/m^2 respectively, the difference being statistically insignificant. The mean heart rate in both groups was 72.0 and 74.0 ($p = -0.45$). Image characteristics of both the groups are shown in ►**Table 2**. Statistically significant differences were seen in the contrast opacifications of AAO and in all the main coronary vessels, with group B patients showing higher opacification. All patients in group A also achieved minimal desirable opacification of more than 350 Hounsfield units (HU) in all the vessels. Group A patients, however, showed a significant reduced image noise with mean of 29 HU (95% confidence interval [CI]: 27.5–30.7; ►**Fig. 1**). Group B patients showed mean noise of 57 HU (95% CI: 54.5–59.6; $p < 0.0001$). The mean S/N and C/N ratios in group A patients were also higher, that is, 20.25, 18.68, 19.04, 17.41, and 18.69 for aorta, left main, left anterior descending, right coronary, and left circumflex arteries (►**Fig. 2A–D**). Group B patients showed mean S/N ratios of 13.34, 11.12, 10.96, 9.74, and 8.67 in AAO, left main, left anterior descending, right coronary artery, and left circumflex artery, respectively. The mean C/N ratios were also higher in all vessels in group A patients, that is,19.48, 19.48, 19.04, 19.48, and 17.68 while group B had 12.43, 10.03, 9.23, 9.57, and 8.23, respectively, for left main, left anterior descending, left circumflex, and right coronary arteries ($p < 0.0001$; ►**Fig. 3A–E**). There were patients with heart rate of more than 95th percentile, that is, more than 86 beats/min; however, good quality images with IQ 4 were obtained in all of them (►**Fig. 4A–C**). Kappa for IOA was 0.84 and 0.63 for per patient and per vessel IQ scores (►**Table 3**). There were 5 patients and 24 vessels from both the groups who had IQ score of 1 and were not assessed while 11 and 9 patients had IQ scores of 3 and 2, respectively (►**Fig. 5A**, **B**). Significant reduction in the radiation dose was seen in group A patients with mean dose of 1.86 mSv while it was 6.89 in group B ($p < 0.001$; ►**Table 4**).

Discussion

The present study showed that lowering the tube voltage to 70 kV obtained a good contrast opacification of the coronary vessels due to positive effect of photoelectric effect with k-edge of iodine being 33 kiloelectronvolt (keV), which was closer to 70 kV than 120 kV. Our study showed a higher contrast opacification in group B patients even as both groups achieved opacification higher than the threshold value of 350 HU. This meant that there was a potential to reduce volume of contrast injected without compromising on IQ. It has been shown that increasing the tube current offsets the negative effect of lowering tube voltage on the IQ.[9] This was shown in the present study by the use of increased tube current using Care Dose 4D protocol by which the tube current was more than doubled to 850 mAs, thus increasing the number of photons as compared with the 120 kV protocol. The increase in tube current also allowed to scan patients with higher BMI up to 31 kg/m^2 as was seen in this study without comprising the contrast and IQ. It was however interesting to observe that SAFIRE-iterative algorithm used in both the group of patients did not show any difference in performance when used with high or low tube potential and the reduction in tube potential from 100 kV to 70 kV resulting in more than 30% increase in noise; this was compensated by increase in the tube current and it was the impact of lowered noise that improved both C/N and S/N ratios while scanning at low peak kilovoltage (kVp). At low tube potential, the influence of the photoelectric effect is greater than Compton scattering effects because of the 33-keV k-edge of iodine[10] and results in increased contrast enhancement while increased tube current lowers the image noise. These two factors combined make examination possible with low-volume injection. Similar results were shown by Kok et al[11] who showed a 56% reduction in injected contrast when low-kV protocol was used. Lell et al[12] also showed in their ex vivo model that optimal contrast can be achieved with reduced iodine dose using 70 kV protocol. This gives many advantages, namely it permits use of lesser gauge intravenous cannulas and reduces the incidence of contrast-induced nephropathy, anaphylactic reactions, volume overloading in cardiac patients, and the cost of consumables per patient. Our study shows that the amount of intravenous contrast can be reduced by half without compromising on IQ.[13,14] The subjective IQ scores in both the groups showed no statistical difference. The present study also showed a

Table 2 Imaging characteristics in group A and group B patients



SNO	GROUP A	95 % CI	GROUP B	95%CI	P VALUE
CAAO	552.5	540.1 to 565.0	950.7	926.0 to 975.5	<0.0001
CLM	536.1	523.8 to 548.3	915.9	875.8 to 929.2	<0.0001
CLAD	527.6	516 to 539.4	902.5	875.8 to 929.2	<0.0001
CLCX	512.9	501.2 to 524.6	913.3	889.1 to 937.5	<0.0001
CRCA	518.5	507.4 to 529.5	916.6	894.2 to 938.9	<0.0001
S/N AO	20.25	19.06 to 21.44	13.34	12.52 to 14.33	<0.0001
S/N LM	18.686	17.863 to 19.51	11.12	10.74 to 11.84	<0.0001
S/N LAD	19.094	18.137 to 20.052	10.96	9.78 to 11.72	<0.0001
S/N RCA	17.870	16.860 to18.75	9.74	9.12 to10.42	<0.0001
S/NLCX	18.69	17.86 to 19.51	8.67	8.14 to 9.83	<0.0001
C/N AO	19.486	18.471 to 20.501	12.43	11.57 to 12.35	<0.0001
C/N LM	19.486	18.471 to 20.501	10.03	9.82 to 11.33	<0.0001
C/N LAD	19.040	18.130 to 20.050	9.23	9.02 to 10.22	<0.0001
C/N RCA	19.486	18.471 to 20.501	9.570	9.090 to 10.050	<0.0001
C/N LCX	17.694	16.784 to 18.604	8.23	7.84 to 9.11	<0.0001
IQ (per patient)					
IQ 3-4	46(92%)		43(86%)		<0.5
IQ 1-2	4(8%)		7(14%)		<0.5
IQ(per vessel)					
IQ 3-4	41(82%)		37(74%)		<0.47
IQ 1-2	9(18%)		13(26%)		<0.45
RAD	1.890		6.40		<0.001

CAAO: Contrast in hounsfield units (HU)in ascending aorta,CLM: Contrast in left main coronary artery,CLCX:contrast in left circumflex artery, CRCA: contrast in right coronary artery, S/N: signal to noise ratio. AO: aorta, LM: left main coronary artery, LCX: left circumflex artery, LAD: left anterior descending artery, RCA: right coronary artery, IQ: image quality, RAD: radiation dose in millisieverts

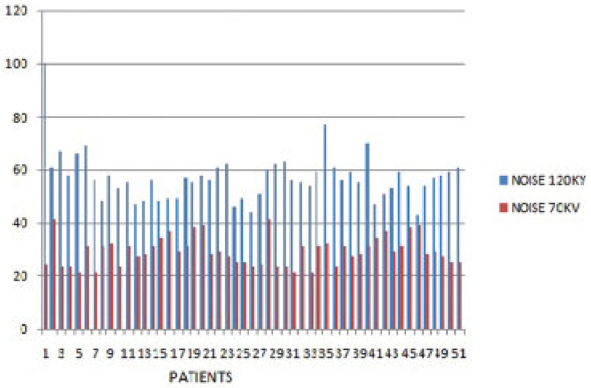


Fig. 1 Bar chart showing image noise in group A and group B patients.

threefold reduction in the radiation dose in group A patients by the use of low-kV protocol. Similar results have been shown by Zhang et al[14] who compared 70 kV protocol with 100 kV protocol. They showed an average dose was 0.38 mSv in patients with BMI of less than 23 kg/m^2 on a dual source CT with prospective ECG gating. Cao et al[15] and Gordic et al[16] also reported that 80 kVp CCTA could reduce up to 57.8% radiation dose for patients (BMI $<$ 23 kg/m^2), as compared with 120 kVp. Our study was different from these studies as we used retrospective ECG gating instead of prospective gating as our patients had higher heart rates as compared with controlled recommended heart rates of 60 beats/min. The radiation dose in our study was slightly higher than these studies due to the selection of retrospective gating. This was due to the nature of outpatient patients and

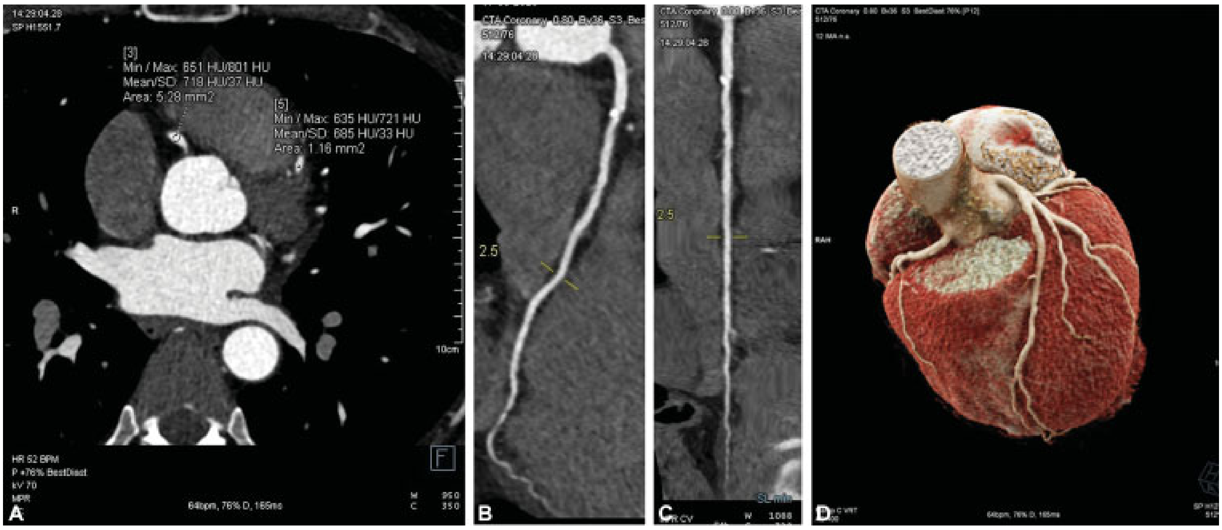


Fig. 2 (**A**) Group A patient with heart rate 65 beats/min axial section at the level of ascending aorta showing signal-to-noise ratio of 19.4 and 20.7 at proximal right coronary artery and proximal left anterior descending coronary artery, respectively. (**B**) Multiplanar view of left anterior descending coronary artery with image quality (IQ) of 4.0. (**C**) Multiplanar view of right coronary artery of same patient with IQ of 4 days. (**D**) Virtual rendering image of same patient.

workflow-related issues, which put constraints of increased waiting time for examination preparation. In spite of the above limitation, our study shows that the use of low-kV protocol reduced the radiation dose threefold even with the use of retrospective gating protocol and provided an optimal IQ. We feel that this protocol offsets the disadvantage of not conducting scans on expensive dual source high pitch or 320 slice single rotation scanners where one has the privilege of using prospective gating protocol even with higher heart rates and thus reducing radiation to below 1 mSv.

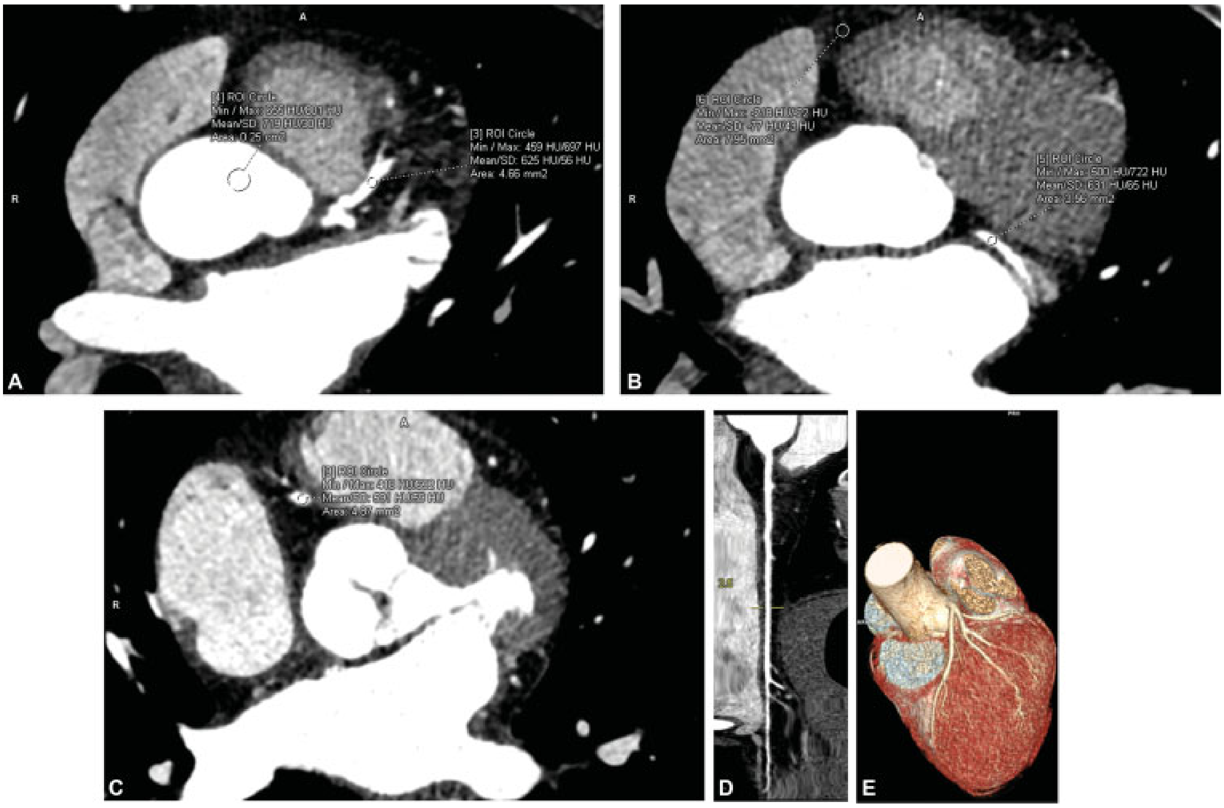


Fig. 3 (**A**) Group B patient showing axial section with signal-to-noise (S/N) ratio of 11.15 of left main and 23.0 of ascending aorta. (**B**) Axial section same patient with S/N of 9.7 of left circumflex artery. (**C**) Axial section of proximal right coronary artery with S/N of 10.0 days. Straightened multiplanar view of left anterior descending artery with image quality score of 4.0. (**E**) Virtual rendering image of heart of same patient.

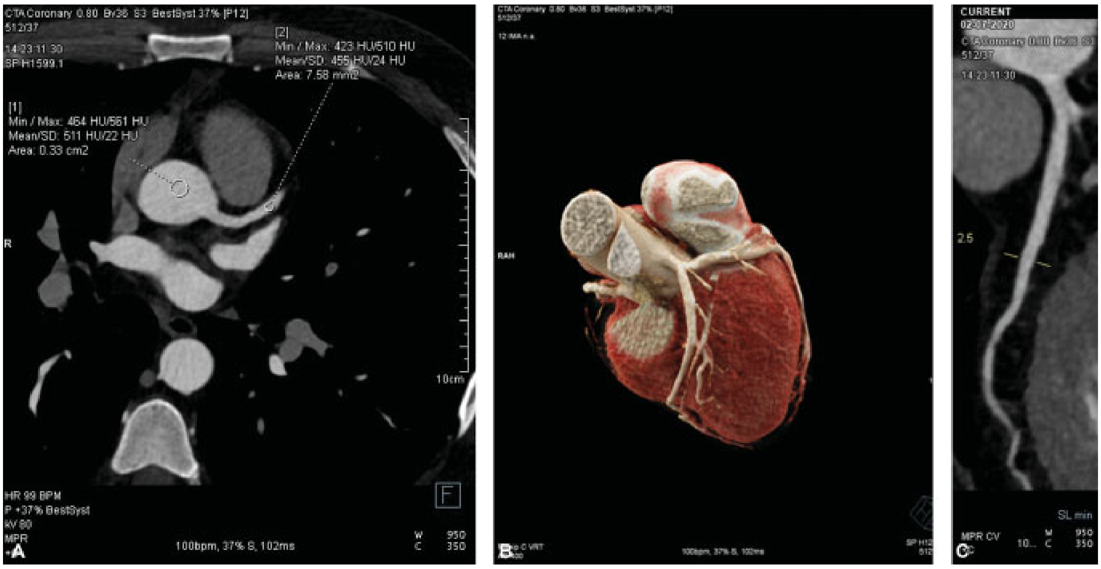
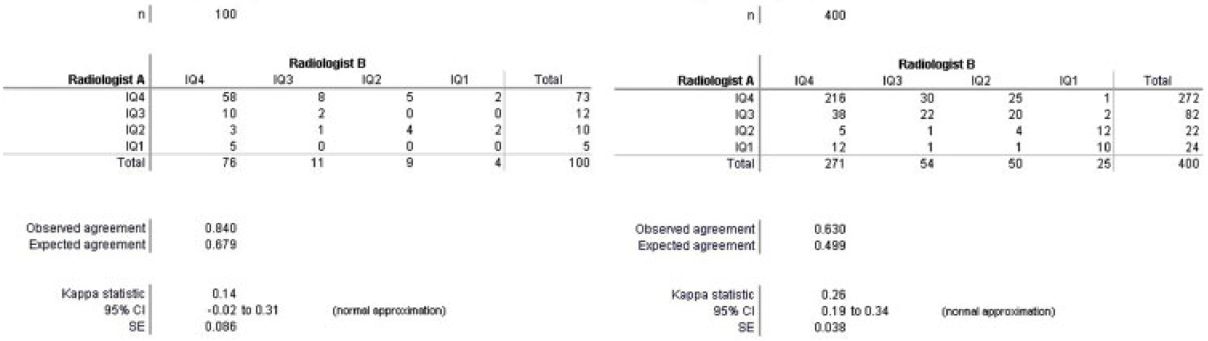


Fig. 4 (**A**) Group A patient with heart rate of 100 beats/min showing signal-to-noise ratio of 25 and 19.5 at proximal ascending aorta and left anterior descending coronary artery, respectively. (**B**) Virtual rendered image of same patient. (**C**) Multiplanar view of left anterior descending aorta with image quality of 4.

Table 3 Kappa statistic for interobserver agreement (A) on per patient basis and (B) on per vessel basis



n	100

	Radiologist B				
Radiologist A	IQ4	IQ3	IQ2	IQ1	Total
IQ4	58	8	5	2	73
IQ3	10	2	0	0	12
IQ2	3	1	4	2	10
IQ1	5	0	0	0	5
Total	76	11	9	4	100

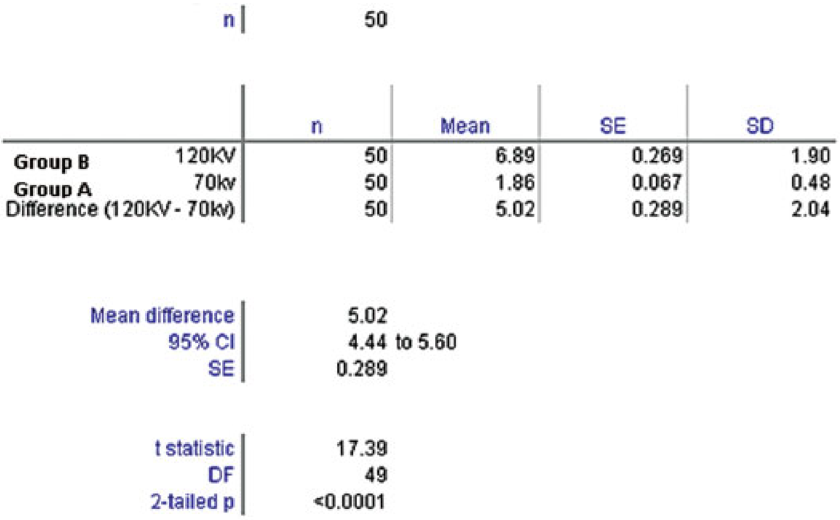
Observed agreement	0.840	
Expected agreement	0.679	
Kappa statistic	0.14	
95% CI	-0.02 to 0.31	(normal approximation)
SE	0.086	

n	400

	Radiologist B				
Radiologist A	IQ4	IQ3	IQ2	IQ1	Total
IQ4	216	30	25	1	272
IQ3	38	22	20	2	82
IQ2	5	1	4	12	22
IQ1	12	1	1	10	24
Total	271	54	50	25	400

Observed agreement	0.630	
Expected agreement	0.499	
Kappa statistic	0.26	
95% CI	0.19 to 0.34	(normal approximation)
SE	0.038	

Table 4 Student's *t*-test for radiation difference in group A and group B patients



n	50

		n	Mean	SE	SD
Group B	120KV	50	6.89	0.269	1.90
Group A	70kv	50	1.86	0.067	0.48
Difference (120KV - 70kv)		50	5.02	0.289	2.04

Mean difference	5.02
95% CI	4.44 to 5.60
SE	0.289
t statistic	17.39
DF	49
2-tailed p	<0.0001

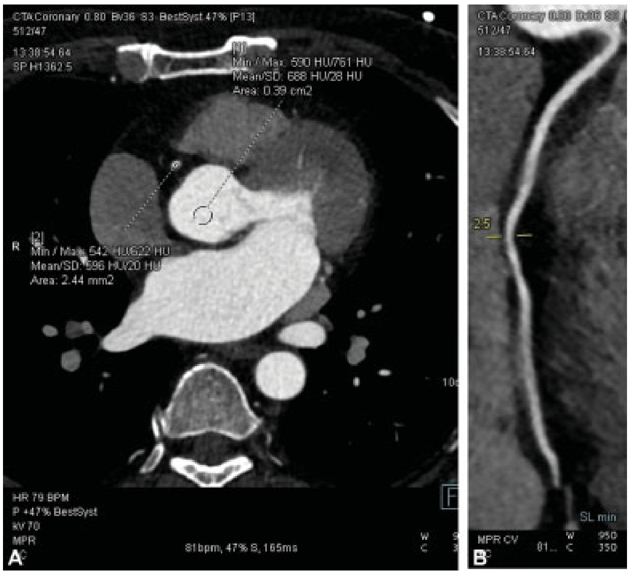


Fig. 5 (**A**) Group A patient with heart rate of 81 beats/min showing signal-to-noise of 28 and 24.5 of proximal right coronary artery and ascending aorta, respectively. (**B**) Multiplanar view of same patient showing image quality of 3 with some vessel wall blurring.

To conclude, the present study shows that low-kV low-dose contrast protocol with retrospective ECG gating not only provides good diagnostic quality angiographic images and reduces radiation dose by threefold compared with 120 kV protocol, but also reduces cost of contrast administered along with reduced risks of using iodinated contrasts. It gives good results in patients with higher BMI up to 31 kg/m^2 and with higher heart rates below 100 beats/min and appears to be a good choice when working on single source scanners.

Declaration of Patient Consent

The authors certify that they have obtained all appropriate patient consent forms. In the consent forms, the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Conflicts of Interest

There are no conflicts of interest.

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