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Evaluation of image quality and radiation dose in low tube voltage coronary computed tomography angiography

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Original Article

Abstract

BACKGROUND: Coronary computed tomography angiography (CCTA) is an important modality in diagnosis of coronary artery disease (CAD). Owing to the fact that computed tomography (CT) examinations are performed using ionizing radiation; applying radiation dose-reduction strategies seems to be necessary. Lowering tube voltage (in kV) according to the patient's body mass index (BMI) or weight is an approach that is investigated by many researchers. The goal of this study was to evaluate the impact of low tube voltage CCTA on radiation dose and image quality in order to decrease radiation dose in selected patients who meet inclusion criteria of the introduced protocol.

METHODS: Patients with clinical indications of CCTA who met inclusion criteria were classified in two groups randomly. Imaging of two groups was performed using 120 kV and 100 kV, respectively. Subjective and objective parameters of image quality and radiation dose of two groups were measured. Afterward, data were analyzed by appropriate statistical tests using SPSS software.

RESULTS: While differences in image quality between two groups were not significant, radiation dose of patients who underwent 100 kV CCTA was significantly lower than the other group. Effective doses (EDs) of first and second groups were 22.30 ± 5.48 mSv and 13.82 ± 2.00 mSv, respectively ($P < 0.001$).

CONCLUSION: Lowering tube voltage in non-obese patients is an effective and practical approach to radiation dose reduction without missing image quality that should be considered especially for female patients.

Keywords: Coronary Angiography, Computed Tomography Angiography, Radiation Dosage, Contrast Agent, X-Rays, Image Enhancement

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Introduction

Coronary artery disease (CAD) is one of the main causes of death throughout the world.[1] Because of changing in lifestyles, CAD seems to be more common in developing countries.[2] Conventional coronary angiography (CCA) is the gold standard modality to evaluate cardiovascular system, but due to its major drawbacks[1] such as invasiveness and high costs,[3] coronary computed tomography angiography (CCTA) is applied as an alternative imaging modality.

Recent advances in multidetector computed tomography (MDCT) including high spatial and temporal resolution and post-processing features result in high-quality images; but the risk of radiation-induced cancer remains as a concern.[4-6] Therefore, there is an interest in low dose CCTA. Owing to this, different approaches such as high-pitch scanning, low tube kilo voltage (kV) technique, and tube current modulation were presented.[7-9]

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As known, radiation dose changes with square of tube voltage; therefore, lowering kV has a considerable effect on patient effective dose (EDs).[10-12] Moreover, low-energy photons underwent more attenuation through photoelectric phenomenon. So because of closing in to the iodine k-edge in contrast agent, vascular enhancement was improved.[11,13,14] The disadvantage of decreasing kV is increasing noise, particularly in obese patients.[15] Therefore, patient's body mass index (BMI) should be considered as an important factor in low kV scanning.

Various studies were done on impact of kV reduction in CTA. Leschka et al. reported that in dual source computed tomography (CT) system, lowering kV from 120 to 100 in normal-weight patients resulted in noise and contrast-to-noise ratio (CNR) increasing beside significant dose reduction.[16] Blankstein et al. stated that using 100 kV instead of 120 kV in dual source scanner with prospective electrocardiography (ECG)-gating method resulted in remarkable radiation dose reductions while image quality remained sufficient.[17] In contrast, Cody et al. recommended 100 kV instead of 80 kV in pediatrics, because of beam hardening artifact in low-energy photons.[18] Zhang et al. evaluated patients with BMI less than 25 kg/m^2 and reported negligible changes in image contrast and noise.[19]

The purpose of this study was to assess the effects of low kV CCTA on patient dose and image quality to achieve an optimum kV for cardiac CT in selected patients.

Materials and Methods

The present study was part of a larger study evaluating the impact of a double-low protocol (low kV and low concentration contrast media) on patient dose and image quality in patients with and without history of coronary artery bypass graft (CABG). 347 patients were referred to perform contrast enhanced CCTA between July 2015 to December 2015 in multislice CT (MSCT) department at Al-Zahra Hospital, Isfahan, Iran. Among them, data of 152 consecutive patients who had maximum BMI of 29 kg/m^2, maximum weight of 90 kg, and calcium score up to 300 Agatston units (AU) were collected prospectively. All the patients were evaluated in terms of heart rate (HR) and glomerular filtration rate (GFR), and if HR was more than 75 beats per minute (bpm), beta blockers were used orally. In this population, those who had history of CABG (n = 23), stent implanting (n = 43), renal failure (n = 14), and patients who could not hold their breath for about 15 seconds (n = 18) were excluded from the study. Then, 54 patients were classified in two groups randomly. First group underwent CCTA using 120 kV and second group scan was performed by 100 kV. Prior to scanning, patients filled informed consent form and a clinical checklist including history of some risk factors.

CCTA was performed on a 64-slice CT scanner (LightSpeed VCT, GE Healthcare, Waukesha, Wisconsin, USA). Whole heart was scanned from tracheal bifurcation to the end surface in craniocaudal direction. Retrospective ECG-gated scan was used with slice thickness of 0.625 mm and gantry rotation time of 350 ms. A window of 70% RR cardiac cycle and pitch factor of 0.22 were applied. Imaging was performed in 4 steps: 1. scout scan to determine field of view (FOV), 2. pre-contrast scans for calcium scoring, 3. timing bolus to schedule contrast media injection setting, and 4. main scan. Typically, 15 ml and 85 ml contrast agent with normal saline were injected during "timing bolus" and "main scan", respectively. Iopamidol 370 (Scanlux) was injected at a rate of 6 ml/s through 18 gauge needle.

ED was calculated through multiplying dose length product (DLP) by tissue weighting factor of region of interest. European working group for guidelines on quality criteria in CT suggested 0.017 $mSv.mGy^{-1}.cm^{-1}$ as chest weighting factor.[20] DLP was measured through multiplying CT dose index (CTDI) by scan length. CTDI can be obtained from scanner console.

Subjective and objective indices of image quality were measured on off-line work station of GE healthcare. Evaluation of subjective image quality parameters was performed by two experienced physicians who were blinded to protocols. Four main coronary arteries including left main (LM), left anterior descending (LAD), right coronary artery (RCA), and circumflex (CX) were scored through a 5-point scale as follows: 1. unreadable: coronary arteries were not valuable, 2. poor: severe artifacts and intense arteries' blurring, 3. fair: medium artifact and moderate blurring, 4. good: slight artifact and negligible blurring, and 5. excellent: without artifact and with high sharpness view.

Objective parameters of image quality including signal-to-noise ratio (SNR), CNR, and noise were measured by drawing a region of interest (ROI) on axial images of arteries. SNR was defined as average attenuation values of RCA and LM divided by noise. CNR was derived from difference between mean attenuation value of proximal segment of LM and the fat tissue adjacent to arteries over noise.

Table 1. Patients characteristics

Patient information	120 kV	100 kV	P
Number of patients	27	27	-
Female gender	6 (22)	17 (63)	0.020
History of high cholesterol	3 (11)	4 (15)	0.680
History of diabetes	1 (4)	4 (15)	0.150
History of high blood pressure	3 (11)	5 (18)	0.440
Age (year)	51.88 ± 14.38	57.88 ± 13.36	0.140
BMI (kg/m²)	25.25 ± 2.47	25.24 ± 2.54	0.940
Calcium score (AU)	34.04 ± 55.25	27.63 ± 61.44	0.170
HR (bpm)	62.47 ± 6.98	60.22 ± 8.50	0.310
Tube current (mAs)	492.59 ± 67.51	492.59 ± 26.68	0.910

Note: Data for 54 patients are presented. Data are presented as n (%) or mean ± standard deviation (SD)
BMI: Body mass index; HR: Heart rate
Mann-Whitney U test and chi-square test were used for quantitative and qualitative parameters, respectively.

Standard deviation (SD) of CT numbers within a circular ROI in left ventricle was considered as noise.[21]

SPSS software (version 22, IBM Corporation, Armonk, NY, USA) was used to analyze data. Quantitative values were expressed as mean ± SD and qualitative parameters were presented as relative frequencies (%). In order to determine the association between qualitative variables of two groups, chi-square test was applied. To evaluate differences of quantitative demographic parameters, radiation dose parameters, and objective indices of image quality among groups, independent t-test was done and Mann-Whitney U test was used if data were not normally distributed. To account for multiple testing influences, Bonferroni correction was performed. P-values less than 0.05 were considered to indicate the statistical significance.

Results

Patients' demographic characteristics were demonstrated in table 1. In 120 kV group, 6 (22%) patients were female, while 17 (63%) patients of 100 kV group's population were female (P = 0.020). Age of patients in 120 kV group and 100 kV group was 51.81 ± 14.38 years (median = 55.00) and 57.88 ± 13.36 years (median = 58.00), respectively (P = 0.140). Distribution of age was normal, while the other variables were not distributed normally. Analyses of calcium score, HR, BMI, and related risk factors plus tube current revealed no significant differences between two groups of patients (Table 1).

Table 2 presents ED, CTDI, and DLP of two groups. Radiation dose of patients who were scanned by 100 kV (13.82 ± 2.00 mSv) were significantly lower compared with the radiation dose of the ones scanned by 120 kV protocol (22.30 ± 5.48 mSv) (P < 0.001). According to table 1, there was no significant difference in tube current between two groups (P = 0.910); therefore, changing radiation dose was directly related to the tube voltage. Lowering kV resulted in reduction of helical and total DLP and finally it decreased patient ED.

Objective parameters of image quality were displayed in table 3. As shown in this table, in 120 kV group noise was significantly lower than the other group (P = 0.003). Because of negligible difference in BMI, it seems that increasing of the noise is only because of kV decreasing. Difference of SNR was not significant, but it was slightly higher in 120 kV group. In contrast, CNR was slightly higher in 100 kV group.

Table 4 shows the number of each score for all segments in both groups. In each of two groups, each of four segments was assessed for 27 patients by 2 observers, so each segment was scored 54 times. Considering data analyzing, LM, LAD, and CX in all cases were found to be sufficient for diagnostic quality. In terms of RCA, two images of 120 kV group were unreadable.

Table 2. Radiation dose of two scanning protocols

X-ray energy	CTDIVOL (mGy)*	Helical DLP (mGy.cm)*	Total DLP (mGy.cm)*	ED (mSv)*
120 kV	58.72 ± 11.45	1218.77 ± 322.73	1311.92 ± 322.73	22.30 ± 5.48
100 kV	36.80 ± 5.06	721.68 ± 108.37	813.28 ± 118.11	13.82 ± 2.00
P**	0.002	< 0.001	< 0.001	< 0.001

CTDIVOL: Volume computed tomography dose index; DLP: Dose length product; ED: Effective dose
* Mean ± standard deviation (SD); ** Mann-Whitney U test was used

Table 3. Assessment of objective parameters of image quality

X-ray energy	SNR*	CNR*	Noise*
120 kV	14.71 ± 4.24	15.87 ± 4.64	29.00 ± 4.24
100 kV	13.62 ± 3.88	16.54 ± 3.95	61.00 ± 24.04
P**	0.194	0.473	0.003

SNR: Signal-to-noise ratio; CNR: Contrast-to-noise ratio
* Mean ± standard deviation (SD)
** Mann-Whitney U test was used; P < 0.050 was considered significant

94.1% of images in 120 kV group and 98.15% of images in 100 kV group had diagnostic value by gaining score of 3, 4, or 5. As shown in table 4, average score of all segments in 100 kV group was slightly better than that in 120 kV groups. In both groups, LM achieved maximum and RCA had minimum average score. Figure 1 demonstrates coronary artery scores for 100 kV and 120 kV; moreover, it shows total subjective image quality of two groups.

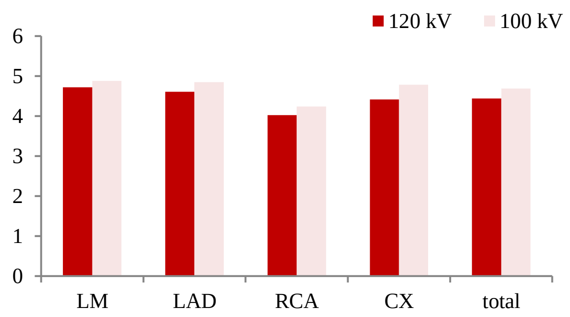

Figure 1. Comparison of subjective image quality between two groups
LM: Left main; LAD: Left anterior descending; RCA: Right coronary artery; CX: Circumflex

Discussion

Among different techniques of dose reduction in CCTA, lowering kV has a considerable effect on patient dose; because radiation dose is related to the square of kV. In the present study, lowering kV from 120 to 100 caused %38 radiation dose reduction. The same pitch factor, slice thickness, tube current (in mAs) and retrospective ECG-gating were used in both groups. Therefore, the amount of reduction in radiation dose is only due to decreasing kV. Basically, reduction in tube voltage is more advantageous than tube current reduction because of two major reasons. First, lowering mAs results in obvious reduction in SNR and beam intensity. Second, radiation dose has a linear relation with mAs and so mAs does not have an important role in decreasing patient dose.

In a number of studies, a comparison between 100 kV and 120 kV in terms of radiation dose and image quality was performed. Lee et al. evaluated 100 kV and 120 kV in patients with history of stent implanting and reported 28% reduction in radiation dose without missing image quality.[22] In another study by Zheng et al., 54% radiation dose reduction was reported in patients with normal BMI.[23] In a similar study by Yang et al., 50% reduction of ED was reported for patients with BMI less than 25 kg/m^2.[24] Khan et al., using 320 row detector to compare 100 kV and 120 kV CCTA, reported 30% reduction in radiation exposure and good image quality in patients with BMI up to 27 kg/m^2.[25] 26% radiation dose reduction and overestimating stenosis of coronary arteries were reported by Marwan et al. who studied use of 100 kV and 120 kV for calcium scan.[26] Acceptable image quality and 40% ED reduction were showed through a study by Ripsweden et al., in which CCTA was performed using 100 kV and 120 kV.[27] 26% increase in image noise and 53% decrease in radiation dose, using 100 kV instead of 120 kV, were reported by Bischoff et al. through a multi-center study.[28] Kidoh et al. showed non-significant differences in ED and image quality between 100 kV with increased mAs and 120 kV.[29] Feuchtner et al. studied patients with BMI < 28 kg/m^2 using 64-slice Siemens scanner and reported 47% reduction in radiation exposure with equal quantitative and qualitative parameters of image quality in 100 kV group.[30]

Table 4. Assessment of subjective parameters of image quality

Image scores		120 kV				100 kV			
		LM	LAD	RCA	CX	LM	LAD	RCA	CX
Number of scores	1	0	0	2	0	0	0	0	0
	2	0	1	6	2	0	0	4	0
	3	3	5	7	7	1	2	5	2
	4	9	8	10	11	4	4	19	7
	5	42	40	29	34	49	48	26	45
Average score		4.72	4.61	4.03	4.42	4.88	4.85	4.24	4.79

For each segment of coronary arteries in each group, 27 patients were studied twice (total number for each segment: 27 × 2 = 54).
LM: Left main; LAD: Left anterior descending; RCA: Right coronary artery; CX: Circumflex
Image quality scores: 1. unreadable; 2. poor; 3. fair; 4. good; 5. excellent

Because of tiny structure and high mobility of heart and its feeding arteries, high quality images of coronary arteries are required to diagnose their anomalies or diseases. Therefore, image quality of low dose protocol should be assessed. Evaluation of four main coronary arteries including LM, LAD, RCA, and CX indicates that subjective image quality of 100 kV is slightly better than 120 kV. For low-energy photons, photoelectric phenomenon is more likely to occur. So, kV reduction and then closing in to the k-edge absorption energy of iodine result in more attenuation and more coronary artery enhancement. Moreover, as a fact, LM gained maximum score among coronary arteries because of its large diameter. RCA achieved minimum score, probably because of its high mobility. Totally, all coronary arteries of both groups had diagnostic values. In terms of objective parameters of image quality, SNR in 120 kV group and CNR in 100 kV group were slightly better than the other group, but differences were not significant. As it was predicted, noise of 100 kV group was significantly higher than 120 kV group. Although this problem did not affect diagnostic value of CCTA images, it should be controlled by using some reconstruction methods such as adaptive iterative dose reduction (ADIR).

Generally, increasing noise due to decrease in photon flux especially in obese patients was considered as a kV reduction drawback. Since patients with cardiovascular disease (CVD) generally have high BMI, modulations of radiation parameters are not considered, whereas pediatrics as well as slim and normal patients should be taken into consideration. So, definition of a radiation protocol for such persons is deemed necessary. As an added disadvantage, beam hardening artifacts may happen because of tube voltage reduction and it limits this technique in patients with history of CABG or stenting and in patients with high calcium score, who were excluded from this study. Finally, 100 kV CCTA in selected patients is suggested as an effective strategy for patient dose reduction without missing image quality.

The present study needs to be assessed in light of some limitations. Our finding showed a significant difference in terms of gender which can make bias. Moreover, according to designed protocol, study was executable only in one imaging center in the province. Furthermore, owing to specific inclusion and exclusion criteria, many patients were not assessed. So, study population was small.

Conclusion

CCTA using 120 kV may impose patients to additional dose. Present study demonstrated that 100 kV CCTA resulted in significant reduction in patient dose without missing diagnostic quality. Thus, for selected patients in terms of BMI, weight, calcium score, stent implanting, and history of CABG, lowering kV is a practical approach to radiation dose reduction.

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Conflict of Interests

Authors have no conflict of interests.

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