SCIENTIFIC RESEARCH

REDUCED IODINATED CONTRAST VOLUME AND RADIATION DOSE IN THE NEW PROTOCOL FOR CT CORONARY ANGIOGRAPHY USING DUAL-SOURCE IMAGING WITH LOW TUBE VOLTAGE COMPARED WITH THE CONVENTIONAL PROTOCOL

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SUMMARY

Objective: To assess the effectiveness and utility of a low-contrast-volume, coronary computed tomography angiography (CCTA) protocol that leverages a lower tube peak voltage (80 kVp) compared to the conventionally employed 120 kVp in patients referred for diagnostic coronary CT angiography.

Materials and Methods: 120 patients (60 males, between 23 to 86 years) were randomly assigned to two groups (n=60) who were scanned with either the 80 kVp (“Group A”) or the 120 kVp (“Group B”) protocols using retrospective ECG gating. All patients had body mass index (BMI) under 25 kg/m2 and heart rates under 120 beats per minute. On a patient-by-patient and segment-by-segment basis, the signal-to-noise (S/N) and contrast-to-noise (C/N) ratios, effective radiation dose given in mSv, and diagnostic confidence (DC) were assessed for both groups by two independent readers with 8 and 7 years experience in coronary CT angiography.

Results: Patients in group A received a significantly reduced radiation dose of 2.57 mSv compared with 7.07 mSv in group B ($p < 0.001$). The total administered amount of Iodine per scan was also significantly lower in Group A (17.5g) than in Group B (24.5g). A significant reduction in image noise with higher S/N and C/N ratios in coronary vessels was seen in group B ($p < 0.001$). S/N ratios in group A were 18.7, 18.6, 18.7, and 18.6 for left main, proximal left anterior descending, proximal left circumflex arteries, and proximal right coronary, respectively, and 16.7, 17.4, and 18.3 for distal left anterior descending, distal left circumflex, distal right coronary arteries, respectively, in group A. Conversely, in group B the S/R values were 22.5, 22.0, 22.0, 21.4,19.0, 18.8, and 21.7 in group B patients. C/N ratios were 22.2, 22.1, 21.9, 22.1, 20.5, 21.0, and 21.9 in group A compared with group B patients, who had ratios of 26.6, 26.1, 25.9, 25.5,

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23.2, 23.0 and 25.6 (in a vessel-by-vessel assessment, each vessel in group B had $p < 0.001$). No significant difference in DC per patient was seen between the groups (ICC 1.0 for Group A and 0.9 for Group B).

Conclusion: The retrospective ECG-gated low-kVp low-volume contrast coronary CT angiography protocol provides angiograms without penalty in diagnostic confidence in patients with BMI up to 25 kg/m2 and heart rates of less than 120 beats/min. It is beneficial for patients whose kidney functions are not good and for those who increased risk for extravasations to diminish the risk of compartment syndrome in severe cases.

Keywords: *coronary CT angiography; low kVp; low contrast volume; radiation*

I. INTRODUCTION

New AHA/ACC, ESC guidelines strongly advocate for the first-line use of CCTA in low-intermediate risk acute chest pain patients, and a majority of stable chest pain evaluations [1,2]. The ability to visualize non-obstructive atherosclerosis, especially vulnerable plaque, allows for earlier initiation of preventive therapies than functional testing, which typically requires a severe stenosis to be present to detect disease. CCTA is also the gold standard noninvasive imaging test to exclude coronary artery disease (CAD) [1]. Further clinical trials, including PROMISE, SCOT-HEART, ISCHEMIA, and DISCHARGE showed the benefits of CCTA [3, 4, 5, 6]. Despite the clinical benefits, the biggest challenge to more widespread adoption of CCTA is radiation dose in younger patients and volume of iodinated contrast for older patients, especially those with impaired kidney function who have a high risk of contrast-associated acute kidney injury (CA-AKI). Risk factors for CA-AKI include diabetes mellitus, dehydration, cardiovascular disease, diuretic use, advanced age, hypertension, hyperuricemia, and multiple iodinated contrast medium doses in a short time interval (<24 hours) [7]. If CCTA can be performed with low radiation and low contrast volume, it will have increased potential to be used in a large number of suspected CAD patients of all ages to exclude or diagnose this disease and treat them appropriately. As a result, multiple protocol adaptations and technological advancements have been developed to help reduce the radiation dose and the volume of contrast.

A well-known approach to reducing radiation dose in CT applications with iodinated contrast media is to lower the tube potential (kV), which exploits the photoelectric effect and in turn the attenuation coefficient of iodine increases as the photon energy decreases towards its K-edge energy of 33 keV. Due to the larger absorption of low-energy photons, images acquired using lower tube potentials tend to be noisier, which can be addressed by using a higher tube current (mA). The ability to supply the required increase in tube current to realize a lower kV protocol depends very much on the technical specifications of the CT system. In this work, we used a CT scanner that is able to produce high tube current in low kV applications hence allowing us to implement this low-dose scanning technique from a technical perspective.

Previous studies have already demonstrated the general benefit of low kV scanning in applications with a lower volume of contrast agent in different body regions and different ethnicities or generally the feasibility of low kV imaging in CCTA [8,9].

The purpose of this study was to assess the image quality acquired by the new protocol (low kV and low contrast) compared to the conventional technique.

II. METHODS

1. Patient Population

A total of 120 patients (60M, 60 F, ages between 23 and 86 years), including outpatients and inpatients, underwent coronary CTA during the surveyed period (Tab. 1). Then they were retrospectively randomly assigned to two groups of n = 60 who were scanned with either 80 kV (“Group A”) or the 120 kV (“Group B”) protocols. All patients had a body mass index (BMI) under 25 kg/m^2 and heart rates under 120 beats per minute.

Inclusive criteria:

- Patients aged> 18 years who have undergone CCTA retrospective ECG at Tam Anh Diagnostic Imaging Center from 4/2021 to 4/2023.
- BMI under 25 kg/m^2
- HR under 120 bpm
- Calcium Score: ≤ 200 (Agatston score)

Exclusive criteria: heart rate > 120 bpm, body mass index (BMI) >25 kg/m^2, severe calcium score, history of arrhythmias, allergy to contrast agents, hyperthyroidism, severe renal or heart dysfunction.

2. Coronary CTA scan protocols

All coronary CTA studies were acquired with SOMATOM Drive 256-acquired slice CT scanner (Siemens Healthineers, Forchheim, Germany) using a retrospectively electrocardiography-triggered technique with automatic exposure control (CareDose 4D).

As for 120 kV in group B, the test bolus technique was applied using 20 mL of contrast medium (Visipaque 320 mgI/mL, Ommipaque 350 mgI/mL, or Xenetix 350 mgI/mL) to synchronize data acquisition with the arrival of contrast material in the aorta. The contrast injection was performed using a power injector through an antecubital vein at a rate of 5-5.5 mL/s with a two-phase protocol: undiluted iodine contrast medium and normal saline. The field of scanning goes from the carina to the end of the heart.

As for 80 kV in group A, the test bolus technique was applied using 10–12 mL of contrast medium (Visipaque 320 mgI/mL, Ommipaque 350, or Xenetis 350 mgI/mL). The contrast injection was performed using a power injector through an antecubital vein at a rate of 3.5–4 mL/s with a two-phase protocol: undiluted iodine contrast medium and normal saline. The field of scanning was from the carina to the end of the heart. Effective radiation dose was calculated by multiplying the dose-length product with the conversion factor for cardiac CT examinations (0.014 mSv/mGy·cm).

Table 1. Scan protocols in the two study groups

Group	kV	Test bolus	Contrast media	Injection rate
A	80	10-12ml	320 mgI/mL 350 mgI/mL	3.5-4 mL/s
B	120	20ml	320 mgI/mL 350 mgI/mL	5-5.5 mL/s

3. Image reconstruction

Images were reconstructed using an iterative reconstruction algorithm (ADMIRE) and a medium-sharp kernel for vascular imaging Bv49. For patients with arrhythmia, the edit ECG technique was applied [10]. Images were then reviewed and analyzed on a dedicated offline workstation (Syngo.via, Siemens Healthineers, Forchheim, Germany).

4. Quantitative analysis

Quantitative measures were performed by measuring the CT attenuation (HU in the lumen of the proximal and distal segments of the major coronary arteries (left main [LM], left anterior descending [LAD], circumflex [LCx], and right coronary arteries [RCAs]). Attenuation was derived from the largest possible circular ROIs within the first 5 mm of the segment (minimum size, more than 2 mm^2) while carefully avoiding the inclusion of the vessel wall and calcification.

The attenuation value was expressed in Hounsfield units (HU). Image noise was determined as the standard deviation (SD) of attenuation measured in the ROIs. The CT attenuation of the pericoronary adipose tissue (PCAT) of respective vessel ROIs was measured as a contrast reference. Consequently, the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated using the following formulas:

$$\text{SNR} = \text{HU(coronary)} / \text{SD(coronary)}$$

$$\text{CNR} = (\text{HU(coronary)} - \text{HU(PCAT)}) / \text{SD(coronary)}$$

These measurements were obtained in one session by a single radiologist (8 years of experience), manually placing a circular region of interest at each aforementioned anatomic site.

5. Qualitative analysis

All scans were independently evaluated for diagnostic confidence (DC) by two experienced readers with 8 and 7 years of experience, respectively, on an off-line workstation (Syngo.via, Siemens Healthineers, Forchheim, Germany).

The score took into account the degree of contrast enhancement in the coronary arteries and the presence of image noise and motion artifacts when assessing the subjective ability to decide on a diagnosis for the given case (Fig. 1). DC was divided into integer values from 0 to 4 analogous to [11]:

0. (nondiagnostic) = significant impairment in image quality because of excessive image noise
1. (poor) = evident limitations in the vessel wall definition owing to poor contrast enhancement of the vessel lumen, blurring of the vessel wall, or severe image noise—acceptable only under limited conditions for the evaluation of a few proximal coronary arteries
2. (good) = minimal limitations in the vessel wall definition owing to low contrast enhancement of vessel lumen, blurring of the vessel wall, or moderate image noise
3. (very good) = well-preserved vessel wall definition with good attenuation of the vessel lumen and minimal image noise

4'.(excellent) = clear vessel wall definition with excellent attenuation of the vessel lumen from the proximal to the distal end and barely perceived image noise— fully acceptable for diagnostic interpretation.

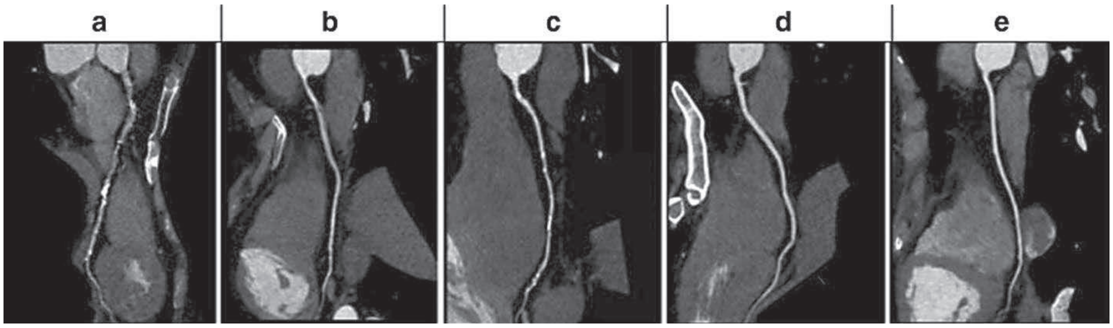

Figure 1. Example images for the respective categories of DC scores. a: DC score 0. b: DC score 1. c. DC score 2. d: DC score 3. e: DC score 4.

Stenosis grading was performed using the Coronary Artery Disease - Reporting and Data System (CAD-RADS) using a consensus approach between two independent readers.

6. Statistical analysis

Analyses were performed using statistical software (SPSS). A statistically significant difference was defined as a P value < 0.05. Continuous variables were expressed as the mean ± standard deviation.

Differences in patient characteristics and quantitative measures of diagnostic confidence between the two groups were tested for significance. A 2-sided *t*-test was applied when the distribution of data from both groups was of equal variance, and a Welch-Satterthwaite *t*-test was used when unequal variance was found. The intra-class correlation coefficient was calculated to describe the inter-rater reliability for the DC score in the two groups of patients. A univariate model was initially applied to determine if there was any link between patient characteristics and SNR.

III. RESULTS

1. Patient demographics

A total of 120 patients referred for coronary CTA (60 males and 60 females) were enrolled in this study and randomly assigned to the low kV scanning protocol or the regular kV protocol. No significant differences were found in body weight and heart rates between the groups. The full overview of patient demographics can be found in Table 1.

Table 2. Overview of patient demographics, clinical parameters, contrast agent and dose parameters for Group A (low kV) and Group B (120 kV).

Group A				Group B		
	Mean	SD		Mean	SD	*P*
Age	56.1	11.8		66.2	11.8	<0.001
SEX [F/M]	28/32			32/28		
BODY WEIGHT [kg]	58.0	7.7		60.4	7.2	0.093
BMI	22.4	1.9		23.8	1.6	<0.001
HEART RATE [bpm]	73.3	11.4		69.4	14.2	0.100
CALCIUM SCORE	5.2	14.3		70.6	32.4	<0.001
CAD-RADS	1.1	1.3		2.1	0.9	<0.001
CTDI vol [mGy]	12.9	2.7		36.6	13.4	<0.001
DLP [mGy*cm]	186.3	40.4		527.0	185.9	<0.001
kV	80.0	0.0		120.0	0.0	
Effective dose [mSv]	2.6	0.6		7.4	2.6	<0.001
Contrast volume [ml]	50.2	4.8		72.8	2.7	<0.001
Iodine amount [g]	17.4	1.8		25.2	1.1	<0.001
Injection flow rate [ml/s]	3.9	0.2		5.0	0.1	<0.001
IDR [mg(I)/s]	1.3	0.1		1.7	0.0	<0.001

* *rows with statistically significant differences between Groups A and B are printed in boldface*

The median age was 55 years ± 11.8 years (standard deviation) for group A and 67 years ± 11.8 years for group B. There was no significant difference in body weight and heart rate between the two groups (all P > 0.05).

2. Radiation dose and contrast media

Patients in group A received a significantly reduced effective radiation dose of 2.6±0.6 mSv compared with 7.4±2.6 mSv in group B (*P*<0.001). Due to the lower injection flow rate used in group A (3.5-4 mL/s) vs. group B (5-5.5 mL/s), a significantly lower total volume of contrast agent was administered to group A compared with group B. On average, patients in group A received 50.2±4.8 mL of contrast agent equaling 17.4±1.8 g Iodine whereas those in group B received 72.8±2.7 mL of contrast agent, which is equivalent to 25.2±1.1 g Iodine. Detailed information can be found in Table 1.

3. Quantitative analysis

Significantly higher signals were recorded in the lumina of all examined coronaries in Group A vs Group B (Fig. 2). While Group A consistently exhibited lumen density values of > 450 HU, the densities in Group B were all below 450 HU on average, yielding significantly lower values in each coronary in a vessel-by-vessel comparison (Table 2). However, in an effort to reduce radiation dose to a minimum without sacrificing image quality, noise levels were higher in group A than in group B, on average by a factor of 1.5. This manifested in slightly, albeit statistically significant, higher S/N and C/N ratios in all coronary vessels across group B (*P*<0.001) as shown in Table 2.

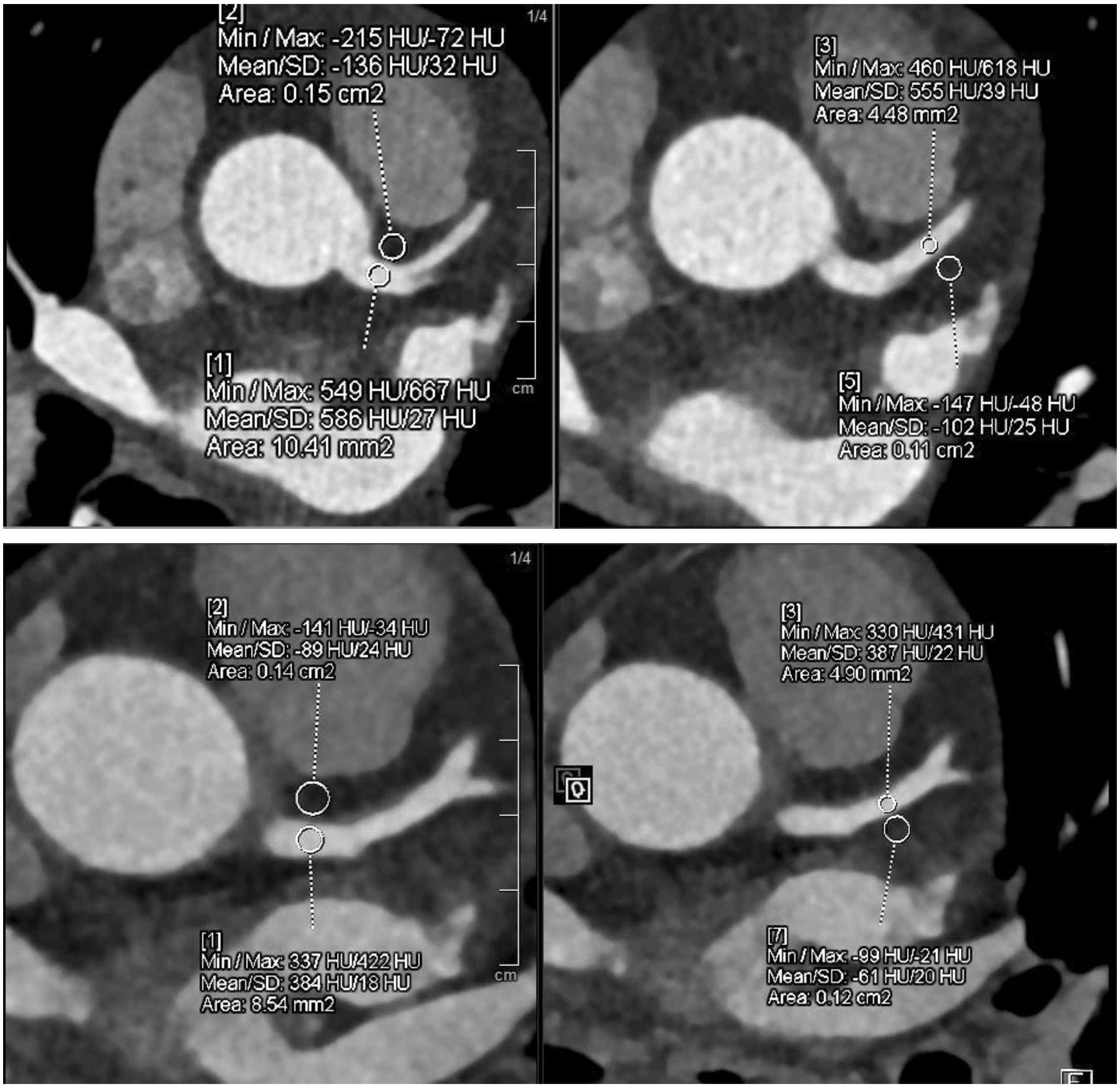

Figure 2. Comparison of representative images showing lumen signal, image quality and ROI placements in two subjects from Group A (top row), and Group B (bottom row). Despite a consistently higher luminal signal in Group A vs Group B, SNR and CNR values were marginally lower on average in Group A.

S/N ratios in group A were 18.7, 18.6, 18.7, and 18.6 for left main, proximal left anterior descending, proximal left circumflex arteries, and proximal right coronary, respectively, and 16.7, 17.4, and 18.3 for distal left anterior descending, distal left circumflex, distal right coronary arteries, respectively, in group A. Conversely, in group B the S/R values were 22.5, 22.0, 22.0, 21.4,19.0, 18.8, and 21.7 in group B patients. C/N ratios were 22.2, 22.1, 21.9, 22.1, 20.5, 21.0, and 21.9 in group A compared with group B patients, who had ratios of 26.6, 26.1, 25.9, 25.5, 23.2, 23.0 and 25.6 (in a vessel-by-vessel assessment, each vessel in group B had *P* < 0.001).

Table 3. Comparison of quantitative and qualitative measures and statistical assessment between Group A (low kV) and Group B (120 kV).

Group A				**Group B**		
	Mean	SD		Mean	SD	*P*
Lumen density LM	581.9	123.9		439.8	86.7	<0.001
Lumen density proximal LAD	562.3	121.6		432.9	89.6	<0.001
Lumen density proximal LCx	578.2	125.9		440.5	88.5	<0.001
Lumen density proximal RCA	586.5	136.5		433.6	93.7	<0.001
Lumen density distal LAD	466.7	111.8		383.1	78.3	<0.001
Lumen density distal LCx	503.3	133.9		367.5	92.0	<0.001
Lumen density distal RCA	566.3	144.2		459.0	100.2	<0.001
SNR LM	18.7	3.4		22.5	6.5	<0.001
SNR proximal LAD	18.6	3.7		22.0	4.8	<0.001
SNR proximal LCx	18.7	3.5		22.0	5.0	<0.001
SNR proximal RCA	18.6	2.9		21.4	4.5	<0.001
SNR distal LAD	16.7	3.8		19.0	4.0	>0.01
SNR distal LCx	17.4	3.2		18.8	4.0	>0.05
SNR distal RCA	18.3	3.3		21.7	3.6	<0.001
CNR LM	22.2	3.8		26.6	7.2	<0.001
CNR proximal LAD	22.1	4.2		26.1	5.1	<0.001
CNR proximal LCx	21.9	3.7		25.9	5.3	<0.001
CNR proximal RCA	22.1	3.1		25.5	4.8	<0.001
CNR distal LAD	20.5	4.4		23.2	4.5	>0.01
CNR distal LCx	21.0	3.3		23.0	4.5	>0.01
CNR distal RCA	21.9	3.6		25.6	3.8	<0.001
Image quality score (Reader 1)	3.8	0.4		3.8	0.5	0.552
Image quality score (Reader 2)	3.8	0.4		3.8	0.5	0.688

** rows with statistically significant differences between Groups A and B are printed in boldface*

4. Qualitative analysis

No significant difference in the diagnostic confidence (DC) score was seen between the groups, while the DC was 3.8±0.4 for group A and 3.8±0.5 for group B (Fig. 3). These scores were underlined by a strong agreement that was found between the readers for both groups (ICC 1.0 for Group A and 0.9 for Group B).

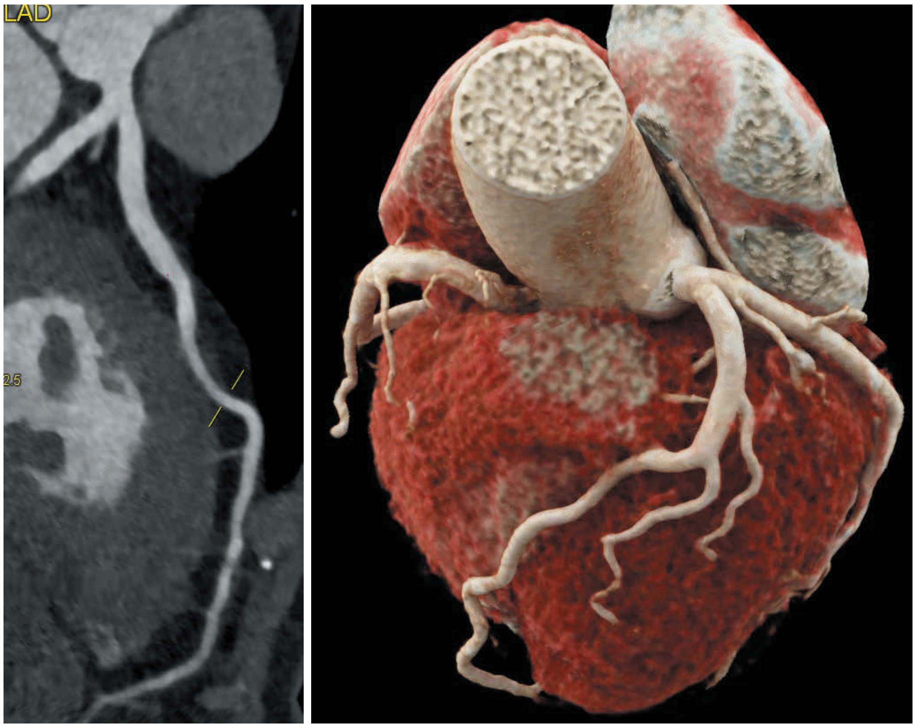

Figure 3. Representative example image of LAD segment (left) and 3D volume rendering (right) of a CCTA scan from Group A.

5. Stenosis assessment

Obstructive CAD (CAD-RADS>2) was diagnosed in 9 of 60 patients in Group A vs. 14 of 60 in Group B (Fig. 4).

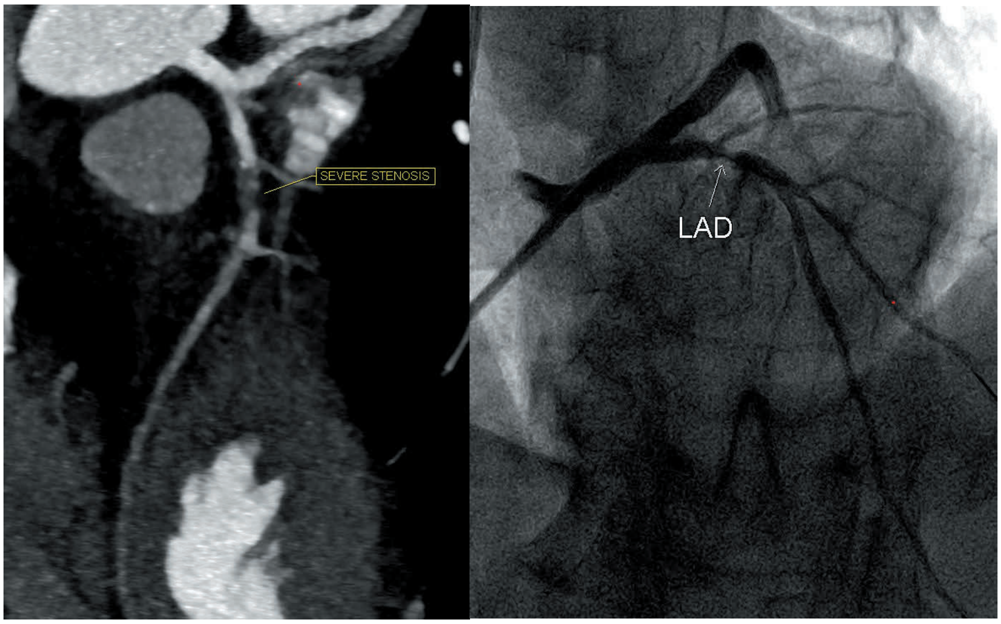

Figure 4. Short segment of a nearly occlusive plaque in the LAD that is nicely visible in low kV and low contrast protocol CCTA (left), presenting the same result as ICA (invasive coronary angiography, right).

IV. DISCUSSION

This study demonstrated that it is possible to lower the volume of iodinated contrast agent in CCTA examination using a “low kV” scanning regime at 80 kV. Another feature worth noticing was that the SNR in the lower kV group showed better achievement. This may be the contribution of the SOMATOM Drive system, which has Care Dose 4D to achieve the required tube currents. In the low kV group, due to the decreased contrast injection rate, which resulted in a lower attenuated intra-arterial HU level, lower CNRs were also observed. While minimally lower SNR and CNR values were obtained in low kV images compared with regular kV images, the diagnostic confidence was non-inferior in low kV scans.

According to ESUR guidelines on contrast agents 10.0, it is recommended for all patients to use low- or iso-osmolar contrast media and the lowest dose of contrast medium consistent with a diagnostic result. For intra-arterial contrast medium administration with first-pass renal exposure, keep either the ratio CM dose (in g/l) / absolute eGFR (in ml/min) < 1.1 or the ratio CM volume (in ml) / eGFR (in ml/ min/1.73 m2) < 3.0, when using a contrast medium concentration of 350 mg/ml [12].

Some research said that intra-arterial administration of contrast material had a similar risk of AKI as compared with that of CT scanning involving IV administration [13]. Therefore, keeping the ratio CM volume/eGFR below 3.0 is necessary.

However, in practicing daily, patients have been clinically advised to perform CT scanning of many parts of the body at the same time despite satisfactory kidney function. For example, scanning the carotid artery and coronary artery, the thoracic and abdominal aortic artery and lower extremities, and whole-body CT for staging cancer and assessing heart disease before surgery. It is very difficult to restrict total contrast volume in these cases to keep the ratio CM volume/eGFR below 3.0 if using scanning protocols with standard tube voltages.

In this work, we successfully demonstrated the clinical utility of using a low kV scanning protocol for CCTA in patients with BMI less than or equal to 25 kg/m2. This allowed us to lower the injection rate and lower the contrast volume.

The retrospective ECG-gated low-kV low-volume contrast CCTA protocol used in this study provides angiograms without penalty to diagnostic confidence in patients with BMIs up to 25 kg/m2 and heart rates of less than 120 beats/min. The protocol also provided an average 2.75-fold reduction in radiation dose and required an average 1.5-fold reduction in contrast volume. The reduced volume of contrast can be used to reduce the cost of the contrast agent as well as the chance of contrast-induced nephropathy. With the ability to use a lower iodine dilution ratio in the low kV protocol, it is also possible to safely rescan patients who might require a rescan right away due to poor image quality caused by, e.g., inadequate holding breath, arrhythmia, or thoracic outlet syndrome. It is also good for patients who have to undergo scanning of multiple parts of the body in one examination. It is beneficial for patients with impaired kidney function, thus improving access to this critical imaging modality for many patients.

V. LIMITATIONS

Our study has a few limitations. Our evaluation focused on quantitative and qualitative measures of image quality without an evaluation of diagnostic accuracy as compared with current gold-standard techniques for detecting coronary artery stenosis, such as invasive coronary angiography. We do, however, note very high agreement in diagnostic confidence between two expert readers and agreement about the diagnosis of obstructive CAD in both groups. In addition, many other protocol adaptations, such as low tube potential scanning, have largely been integrated based on studies documenting preserved image quality and interpretability in other body parts before.

Furthermore, the coronary CTA scans in our study were evaluated by highly experienced coronary CTA readers. We performed our analysis on a per-vessel basis, including the left main coronary artery, proximal right coronary artery, left anterior descending, left circumflex, distal right coronary artery, left anterior descending, and left circumflex. Therefore, our data are meant to serve as a proof of concept and are exploratory, which suggests that low-kV and low-contrast dual-energy coronary CTA may be a reasonable alternative to standard coronary CTA in patients, especially those at risk of CIN.

One main limitation for the comparability of our research is that we chose patients with a BMI less than or equal to 25 and no severe calcification. While 2this represents the typical patient population in our hospital, and potentially also the wider southeast Asia, it may not be reflective of typical patient cohorts in other regions.

VI. CONCLUSION

The result of the research provides many benefits for patients with impaired kidney function, especially those who have to rescan right away due to poor image quality, those who have to scan many parts of the body at the same time, those whose veins are difficult to inject an 18-gauge needle for an injection rate of 5–5.5 ml/s of the standard protocol, and lastly, those who have an increased risk for extravasations to diminish the risk of compartment syndrome in severe cases.

REFERENCES

1. Martha Gulati, Leslee J. Shaw, et al., 2021 AHA/ACC/ASE/CHEST/SAEM/SCCT/SCMR Guideline for the Evaluation and Diagnosis of Chest Pain: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines, Originally published 28 Oct 2021; https://doi.org/10.1161/CIR.0000000000001029. Circulation. 2021;144: e368–e454.
2. Saraste A, Knuuti J. ESC 2019 guidelines for the diagnosis and management of chronic coronary syndromes: Recommendations for cardiovascular imaging. Herz. 2020 Aug;45(5):409-420. DOI: 10.1007/s00059-020-04935-x. PMID: 32430520; PMCID: PMC7391397.
3. Pamela S. Douglas, M.D., Udo Hoffmann, M.D., et all for the PROMISE Investigators, Outcomes of Anatomical versus Functional Testing for Coronary Artery Disease, N Engl J Med 2015; 372:1291-1300, DOI: 10.1056/NEJMoa1415516.
4. The SCOT-HEART Investigators, Coronary CT Angiography and 5-Year Risk of Myocardial Infarction, N Engl J Med 2018; 379:924-933, DOI: 10.1056/NEJMoa1805971.
5. David J. Maron, M.D., Judith S. Hochman, M.D, et al. for the ISCHEMIA Research Group, Initial Invasive or Conservative Strategy for Stable Coronary Disease, N Engl J Med 2020; 382:1395-1407, DOI: 10.1056/NEJMoa1915922.
6. The DISCHARGE Trial Group, CT or Invasive Coronary Angiography in Stable Chest Pain, N Engl J Med 2022;386:1591-1602 DOI: 10.1056/NEJMoa2200963.
7. Carolyn Wang et al. ACR manual on contrast media. 2023.
8. Choi, M.-H.; Lee, Y.-J.; Jung, S.-E. The Image Quality and Diagnostic Performance of CT with Low-Concentration Iodine Contrast (240 mg Iodine/mL) for the Abdominal Organs. Diagnostics 2022, 12, 752. https://doi.org/10.3390/diagnostics12030752.
9. Jun BR, Yong HS, Kang EY, Woo OH, Choi EJ. 64-slice coronary computed tomography angiography using low tube voltage of 80 kV in subjects with normal body mass indices: comparative study using 120 kV. Acta Radiol. 2012 Dec 1;53(10):1099-106. doi: 10.1258/ar.2012.110573.
10. Robert Pelberg, Wojciech Mazur, Cardiac CT Angiography Manual, book, Springer, Jul 2007.
11. Jia CF, Zhong J, Meng XY, Sun XX, Yang ZQ, Zou YJ, Wang XY, Pan S, Yin D, Wang ZQ. Image quality and diagnostic value of ultra low-voltage, ultra low-contrast coronary CT angiography. Eur Radiol. 2019 Jul;29(7):3678-3685. doi: 10.1007/s00330-019-06111-0. Epub 2019 Mar 19. PMID: 30888481.
12. Henrik S. Thomsen et al. ESUR guidelines on contrast agents 10.0. 2018.
13. McDonald, Jennifer S. PhD; Leake, Caleb B. BS; McDonald, Robert J. MD, PhD, et al., Acute Kidney Injury After Intravenous Versus Intra-Arterial Contrast Material Administration in a Paired Cohort. Investigative Radiology 51(12): p 804-809, December 2016. | DOI: 10.1097/RLI.0000000000000298.

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