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Comparison of some baseline variables and radiation exposure between prospective and retrospective electrocardiography-coupled coronary CT angiography protocols: A single-center observational study

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ABSTRACT

Aim: To compare the radiation doses received by patients undergoing coronary computed tomography (CT angiography) using prospective and retrospective electrocardiogram (ECG) simultaneous protocols, considering factors such as age, gender, body mass index, heart rate, and Agatston calcium score. **Methods:** A total of 80 patients (heart rate: 45–78 bpm) were retrospectively evaluated. Forty-two (42) patients underwent prospective ECG-gated scanning, and thirty-eight (38) underwent retrospective ECG-gated scanning. Patients' age, gender, body mass index (BMI), Agatston calcium score, dose-length product (DLP), and effective dose (mSv) were recorded. The effective radiation dose (mSv) was calculated by multiplying the DLP by a conversion coefficient of 0.014. The scanner utilized radiation dose-reduction technologies, including CARE kV algorithms, X-CARE (Organ-Based Dose Modulation), CARE Dose 4D and Tin Filter.
Results: The mean effective radiation doses were recorded as 1.54 mSv for the prospective cohort and 2.85 mSv for the retrospective cohort. While no statistically significant disparity was observed based on gender, a weak positive correlation was detected between patient age and radiation dose ($r=0.09$, $p<0.05$). **Conclusion:** Prospective ECG-triggered acquisition yields significantly lower radiation exposure than retrospective protocols, contingent upon rigorous patient selection and the maintenance of appropriate heart rate limits. Irrespective of the scanning technique employed, a positive correlation was established between effective radiation dose and both Body Mass Index (BMI) and heart rate, whereas no statistically significant association was found regarding age or gender. While the relationship between Agatston score and effective dose appeared more distinct within the retrospective cohort, it presented only a weak positive correlation that failed to reach statistical significance.

Keywords: Coronary artery disease (CAD), coronary computed tomography angiography, radiation dose, ECG-gated protocols.

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1. Introduction

Coronary artery disease (CAD) remains a leading cause of global morbidity and mortality. Coronary Computed Tomography Angiography (CCTA), a non-invasive imaging modality, has gained prominence due to its ability to provide both anatomical and functional information [1,2]. However, because it involves exposure to ionising radiation, careful protocol selection is particularly important in younger and low-risk populations [3,4].

One of the most influential determinants of radiation dose during CCTA is the type of ECG-gated acquisition: Retrospective ECG gating involves continuous helical scanning throughout the cardiac cycle, allowing functional assessment but resulting in higher radiation doses [5,6]. Prospective ECG triggering, on the other hand, restricts data acquisition to specific phases of the cardiac cycle (typically mid-diastole), substantially reducing radiation exposure [7]. This technique is best suited for patients in a stable sinus rhythm with controlled heart rates [8].

As can be understood from the defined technical parameters, for the same imaging procedure, the retrospective method prolongs the patient's exposure time to X-rays by extending the scan duration. Conversely, in the prospective method, this duration is shortened, thereby reducing the patient's total radiation dose resulting from X-ray exposure [9]

The recently introduced Siemens Go.Top device, along with CARE kV algorithms, CARE Dose 4D, X-CARE (Organ-Based Dose Modulation)) software and Tin Filter technologies, has been designed to deliver low doses [10].

The aim of this study is to evaluate, in a clinical patient sample, the effect of patient age, sex, body mass index (BMI), calcium score, and basal heart rate on the radiation dose during CCTA scans performed with the Siemens Go.Top (Siemens Healthcare, Forcheim, Germany) device using these two protocols, and to compare the results with the current literature.

2. Materials and methods

2.1. Study Design*:* This retrospective study was conducted at a single centre (Private Ataşehir Avicenna Hospital/Istanbul) and included 80 patients of different ages, body mass index (BMI) and gender, imaged with Siemens Go.Top (Siemens Healthcare, Forcheim, Germany) between February 2021 and June 2025. Prior to Coronary Computed Tomography Angiography (CCTA), all patients underwent non-contrast spiral CT calcium scoring, with Agatston scores calculated to assess plaque burden and guide protocol selection [3,11]. This scoring also contributed to radiation optimisation strategies.

In our study, the relationship between the effective radiation dose exposure and the parameters of acquisition protocol, age, sex, body mass index (BMI), heart rate, and calcium score was investigated and compared with the existing literature. As far as we could ascertain, there are limited studies in the literature that compare the effective radiation dose with the simultaneous use of all the parameters we employed. This distinction highlights the novelty of our work and, we believe, contributes significantly to the current body of literature [12-15].

In patients with a heart rate exceeding 65 beats per minute (bpm), 5 mg of intravenous metoprolol was administered on the scanning table to reduce the heart rate, concurrently with blood pressure monitoring [16]. In patients with persistently elevated heart rates where the target reduction was not adequately achieved, the dose was safely and incrementally increased up to a maximum of 15 mg.

Patients with arrhythmias such as atrial fibrillation and frequently recurring extrasystoles, those with respiratory distress unable to hold their breath for the entire acquisition period (approximately 15 seconds), and patients with a calcium score exceeding 1000, which can result in diagnostic difficulty due to intense artifacts, were excluded from the study.

The institutional ethics committee approved the study, and all patient data were anonymised. CCTA scans were performed using the Siemens SOMATOM Go.Top (2021, Siemens Healthcare, Forchheim, Germany) equipped with CARE kV, CARE Dose 4D and X-CARE (Organ-Based Dose Modulation) software. Tube filtration was accomplished using a thin tin filter [17-19].

For the CCTA examinations, parameters for both the prospective and retrospective Electrocardiography (ECG)-gated protocols were set as follows: 0.625 mm collimation, a gantry rotation time of 0.33 s, 140 kV tube voltage, and 625 mA tube current.

The radiation dose received by the patients was automatically provided by the Computed Tomography (CT) scanner immediately after the acquisition as the Dose Length Product (DLP), with the unit of mGy·cm. The obtained DLP, value was then converted to Effective Dose in mSv (miliSievert) using region-specific conversion coefficients (k-factors), which are determined based on the radiosensitivity of the exposed organs. This coefficient system is based on the tissue weighting factors recommended by the International Commission on Radiological Protection (ICRP) and the specific geometry of the Computed Tomography scan region. In ICRP data, this coefficient is specified as 0.014 for the adult thorax region. Accordingly, effective doses in mSv were calculated in this study by multiplying the DLP values by the 0.014 coefficient: Effective Dose (mSv) = DLP (mGy·cm) × 0.014 [20].

Retrospective ECG gating was employed for data acquisition, with continuous radiation exposure maintained throughout the entire cardiac cycle. This technique allowed for image reconstruction across all phases, thereby providing comprehensive data on coronary arteries during both systole and diastole. Although this protocol resulted in a higher radiation dose due to the extended exposure time, it was essential for diagnostic assessment as it enabled the visualization of all coronary segments regardless of the cardiac phase. Consequently, this method was specifically utilized for patients presenting with heart rates >65 bpm, calcium scores >400, or those with limited breath-holding capacity.

In the prospective triggering technique, data acquisition is timed to the R-R interval corresponding to the diastolic phase, when the heart is relatively quiescent. The resulting data is limited exclusively to the diastolic phase of the cardiac cycle. This methodology reduces the acquisition time and, consequently, the radiation dose exposure. Therefore, this technique is considered ideal for patients in sinus rhythm whose heart rate is stable and <65 bpm.

2.2. Statistical Analysis*:* Data were analysed using SPSS version 24.0. Student's t-test was used for parametric comparisons, and the Mann–Whitney U test for non-parametric data. The prediction of the radiation dose based on age, gender, body mass index (BMI), calcium score, and heart rate was assessed using regression analysis, while the correlations between these parameters and the dose were determined using Pearson’s correlation analysis. A *p*-value < 0.05 was considered statistically significant.

3. Results

The patient cohort included in the study was limited to a total of 80 individuals, comprising 54 males and 26 females. The patients' ages ranged from 27 to 80 years, with a mean age of 55.2 ± 12,7 years. During the acquisition, the patients' heart rates varied between 45 and 78 bpm (Table 1).

In the regression analysis including age, sex, heart rate, calcium score, and BMI, age and sex did not have a significant effect on the effective radiation dose, whereas heart rate, calcium score, and body mass index demonstrated significant effects. A moderate-to-strong positive correlation was observed between radiation dose and body mass index (r = 0.56, *p* = 0.05), while no significant correlation was

Table 1. Basic characteristics of the patient population.

Characteristic	**Value**
Total Number of Patients	80
Gender (Male / Female)	54 / 26
Age (mean ±SD (range))	27-80 (55.2 ± 12.7)
Mean heart rate, bpm	45–78 bpm
Exclusion Criteria	Atrial fibrillation, frequent extrasystoles, inability to hold breath (~15 seconds), calcium score >1000

* ***mean:*** *average; ****SD:*** *standard deviation;****bpm*** *- beats per minute.*

detected between radiation dose and age (r = 0.09, *p*= 0.40). There was a strong positive correlation between age and BMI (r = 0.76, *p* = 0.02) and a moderate positive correlation between heart rate and BMI (r = 0.44, *p* = 0.05). In this study, no statistically significant difference in effective dose was found between male and female patients across both the prospective and retrospective groups (*p* = 0.427) [22].

Patients with arrhythmias such as atrial fibrillation and frequently recurring extrasystoles, those with respiratory distress unable to hold their breath for the entire acquisition period (approximately 15 seconds), and patients with a calcium score exceeding 1000, which can result in diagnostic difficulty due to intense artifacts, were excluded from the study.

While there was no significant difference in age between the prospective and retrospective acquisition protocol groups, the gender difference exhibited a tendency toward being higher in the prospective group. Conversely, body mass index (BMI) and basal heart rate were significantly higher in the retrospective group [21]. The mean Dose Length Product (DLP) (114.2 ± 58.9 mGy·cm vs. 181.5 ± 73.4 mGy·cm) and Effective Doses (1,60 ± 0.82 mSv vs. 2.54 ± 1.03 mSv) were significantly lower in the prospective group when compared to the retrospective group (Table 2).

In all patients included in our study, the relationship between age and dose was positive for both protocols independently and collectively, irrespective of the acquisition technique. However, this difference (*p*=0,409) was not found to be statistically significant.

The number of patients with a heart rate exceeding 65 bpm was statistically significantly higher (*p*<0.001) in the retrospective group compared to the other group. Furthermore, the effective radiation dose in this same high heart rate patient cohort was also found to be

Table 2. Imaging protocols and radiation dose parameters.

Parameters	**Prospective ECG-Gated CT (n = 42)**	**Retrospective ECG-Gated CT (n = 38)**	***p*-value**
Age (years ±SD (range))	53.6 ± 10.6	55.3 ± 11.3	0.409
Gender (male/female)	30 / 12	24 / 14	0.427
Body Mass Index (kg/m²)	26.2 ± 4.4	29.3 ± 5.2	0.04
Baseline heart rate (beats/min)	55 ± 8	66 ± 12	<0.001
Mean DLP (mGy·cm)	114.2 ± 58.9	181.5 ± 73.4	<0.001
Mean Effective Dose (mSv)	1.60 ± 0.82	2.54 ± 1.03	<0.001
Number of patients	42	38	>0.05
Calcium score	68.76 ± 102.90	69.3 ± 120.18	0.988

** **mean:** average; ***SD:** standard deviation;***bpm** - beats per minute; ***BMI:** Body Mass Index; * **mSv**: milliSievert; **n**:number of participants**; p <0.05**: statistically significant.*

significantly elevated (*p*<0.001). It is hypothesized that the selection of the retrospective technique is the most significant factor contributing to the higher effective radiation dose in patients with high heart rates [23-25].

The number of patients aged over 60 years in our study totaled 33, with 15 undergoing the prospective technique and 18 the retrospective technique. While the difference was not statistically significant, it exhibited a tendency to be higher favoring the retrospective group. The under 60 years cohort totaled 47 patients, where 27 utilized the prospective technique and 20 the retrospective technique. Contrary to the older cohort, this difference, though also not statistically significant, showed a tendency favoring the prospective group. There was no statistically significant correlation between the over 60 and under 60 age cohorts (r=0.11, *p*=0.29). When effective doses were evaluated irrespective of the protocol in the two age groups (1.98 mSv vs. 1.99 mSv), no statistically significant difference was found (r=0.005, *p*=0.98); however, the inclusion of patients in the retrospective group alone significantly contributed to the overall dose increase.

A calcium score greater than zero (>0) was found in 37 (%46.25) of the patients included in the study. The mean Agatston score was slightly lower in the prospective group (68.76 ± 102.90) compared to the retrospective group (69.3 ± 120.18), although no statistically significant difference was observed between them (*p*>0.05). (Table 2)

In our study, a weak positive correlation (r = 0.185, p = 0.099) was found between the calcium score and the effective dose (mSv - millisieverts), irrespective of the acquisition protocol, although this relationship was not statistically significant. Protocol-based analysis revealed a very weak positive correlation in the prospective protocol (r = 0.135, *p* = 0.378) and a weak positive correlation in the retrospective protocol (r = 0.192, *p* = 0.270); however, neither correlation reached the level of statistical significance.

4. Discussion

The findings of this study demonstrate that the prospective protocol is the most significant parameter for achieving a low radiation dose during Coronary Computed Tomography Angiography (CCTA) scans performed with the

Siemens Go.Top device. The positive association between increasing age and higher dose may be attributed to the typically higher Body Mass Index (BMI) and heart rate observed in older age cohorts. Furthermore, the tendency of a higher calcium score to lead to an increase in effective dose can also be considered a major contributing factor to the non-statistically significant slight dose elevation seen in the older patient groups. Another significant finding, consistent with the literature, is that gender difference did not result in a statistically significant change in radiation doses [26,27].

The radiation doses reported in this study (1.60 ± 0.82 mSv (milliSievert) and 2.54 ± 1.03 mSv (milliSievert)) are notably lower when compared to the dose ranges previously published in the literature. Specifically, the mean dose for prospective CCTA is generally reported as 1.8 mSv in the literature and retrospective scans are reported to range between 3.5 and 8.0 mSv [5,28,29]. The low radiation dose achieved with the prospective ECG-triggered protocol is consistent with and further supported by the advanced dose-reducing technologies of the Siemens Go.Top device [10] . Literature reports the average dose with the Siemens Go.Top system to be 1.2-1.6 mSv [30]. When comparing our dose values obtained using the prospective protocol 1.60 ± 0.82 mSv (milliSievert) with published doses from both the Siemens Go.Top and other devices, no statistically significant difference was found ($p>0.05$). Conversely, the dose values achieved with the retrospective ECG-triggered protocol (2.54 ± 1.03 mSv) were significantly lower ($p<0.001$) than the values reported in the current literature. This favorable outcome is attributed not only to the advanced dose-reducing software of the Siemens Go.Top device (CARE Dose 4D, CARE kV, X-CARE (Organ-Based Dose Modulation) and Tin Filter algorithms), but also to our study criteria, specifically the exclusion of patients with high calcium scores (>1000) and the meticulous control of heart rate achieved through beta-blocker administration [3,31,32].

The Siemens Go.Top device, utilizing CARE Dose 4D, CARE kV, X-CARE (Organ-Based Dose Modulation) and Tin Filter algorithms, enables CCTA acquisition using the prospective technique with effective radiation doses capable of dropping below 1 mSv (The lowest dose in our study was 0.35 mSv). However, achieving this dose advantage requires appropriate patient selection and rhythm stability.

The higher effective dose in the retrospective protocol is an expected finding. In our study, the retrospective protocol was preferentially used in patients over 60 years of age, though this preference did not reach statistical significance. This selection was based on clinical factors such as relatively high basal heart rates (bpm), the presence of rare extrasystoles, a calcium score exceeding 400, and difficulty with breath-hold control. The literature has demonstrated that the mean radiation dose is significantly elevated in patients with a high calcium score, due to the increased artifacts and image noise [33] A Coronary Artery Calcium Score (Agatston score) of 400 or greater indicates moderate coronary artery calcification and may negatively impact the image quality of CCTA [34]. This situation typically necessitates the use of parameters such as a higher tube current or an extended scanning duration to maintain diagnostic accuracy, thereby potentially leading to an increase in the effective radiation dose. Furthermore, it has been reported that advanced calcification reduces the efficacy of automatic tube current modulation systems, and consequently, low-dose protocols have limited applicability in this patient cohort [35].

An important finding, consistent with the literature, is the absence of a statistically significant effect of gender difference and age on radiation doses, outside of the acquisition protocol, body mass index and heart rate. However, a weak positive correlation between the calcium score and effective dose was observed in our study, which was more pronounced in the retrospective protocol, yet did not reach the level of statistical significance [36]. We hypothesize that the deviation of this finding from the existing literature stems from our decision to set the calcium score threshold at 400. Although not statistically significant, the weak positive correlation observed in our study between the calcium score and effective dose does not contradict the established knowledge that an increase in calcium plaque burden leads to a resultant increase in effective dose.

In a multicenter study conducted by Hausleiter et al., a weak but significant negative correlation (r = –0.21, p = 0.03) was detected between age and effective dose, indicating a slight reduction in effective dose as age increased [26]. Similarly, another study reported a significant negative correlation between age and effective dose (r = –0.19, p = 0.04) [37]. Our study also observed a comparable trend, showing a minimal dose reduction with increasing age (1.98 mSv vs. 1.99 mSv), irrespective of the acquisition protocol.

In a study conducted by Einstein et al., [38] the mean effective dose in females was reported to be %8-10 higher than in males, though this difference was only borderline statistically significant (p = 0.06). The same study also reported that due to the additional dose absorbed by the breast tissue in female patients, the mean effective dose was slightly higher compared to males, even when identical technical parameters were employed. In contrast, a study with a larger sample size conducted by Maruyama et al. [39] reported that the female sex showed a significant positive correlation with the effective dose (r = 0.27, p = 0.01).

In our study, a minimal negative correlation was observed in the effective dose received by females, which was not statistically significant (p=0.427). We hypothesize that this result is attributable to the dose-reducing algorithms of the Siemens Go.Top device, specifically the breast-sparing protocol X-CARE (Organ-Based Dose Modulation) used in every scan.

The limitations of this study include its single-center design, an insufficiently high patient count, the lack of quantitative image quality assessment, and the inability to compare results with the gold standard, conventional angiography.

4.1. Conclusions

There is a paucity of research in the literature that compares effective radiation doses in Coronary Computed Tomography Angiography (CCTA) using both prospective and retrospective ECG-gated protocols while simultaneously analyzing five distinct parameters: age, gender, body mass index (BMI), heart rate, and calcium score. Therefore, notwithstanding its limitations, we believe that this study makes a significant contribution to the existing body of knowledge by addressing this gap. For patients characterized by appropriate heart rates and low calcium burdens (<400 Agatston), prospective ECG-gated CCTA offers a significant advantage in terms of radiation dose reduction. Such a benefit directly influences clinical algorithms, favoring this technique for young and low-risk cohorts to ensure safer diagnostic imaging. Consistent with existing literature, our results demonstrate that elevated Body Mass Index (BMI), heart rates, and Agatston scores (>400) are associated with a significant increase in effective radiation dose, independent of the selected acquisition protocol. Conversely, no statistically significant correlation was found regarding age or gender. The observed rise in radiation exposure among patients with Agatston scores of 400 or higher can be attributed to the technical adjustments necessary to maintain optimal image quality and diagnostic accuracy in the presence of severe calcification. The integration of advanced dose-reduction software and hardware in the Siemens Go.Top system further enhances radiation safety while maintaining high diagnostic quality. While the single-center nature and sample size limit generalizability, future multicenter studies with larger cohorts are warranted to validate and expand upon these findings.

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References

[1]Budoff MJ, Dowe D, Jollis JG, et al. Diagnostic performance of 64-multidetector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease: results from the prospective multicenter ACCURACY (Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. J Am Coll Cardiol. 2008;52(21):1724-32.

[2]Bischoff B, Hein F, Meyer T, et al. Comparison of sequential and helical scanning for radiation dose and image quality: results of the Prospective Multicenter Study on Radiation Dose Estimates of Cardiac CT Angiography (PROTECTION) I Study. AJR Am J Roentgenol. 2010;194(6):1495-9.

[3]Hecht HS. Coronary artery calcium scanning: past, present, and future. JACC Cardiovasc Imaging. 2015;8(5):579-596.

[4]Raff GL, Abidov A, Achenbach S, Berman DS, Boxt LM, Budoff MJ, Cheng V, DeFrance T, Hellinger JC, Karlsberg RP; Society of Cardiovascular Computed Tomography. SCCT guidelines for the interpretation and reporting of coronary computed tomographic angiography. J Cardiovasc Comput Tomogr. 2009;3(2):122-36.

[5]Hausleiter J, Meyer T, Hadamitzky M, et al. Radiation dose estimates from cardiac multislice computed tomography in daily practice: impact of different scanning protocols on effective dose estimates. Circulation. 2006;113(10):1305-10.

[6]Fuchs TA, Stehli J, Bull S, et al. Coronary computed tomography angiography with model-based iterative reconstruction using a radiation exposure similar to chest X-ray examination. Eur Heart J. 2014;35(17):1131-6.

[7]Cademartiri F, Maffei E, Palumbo AA, et al. Influence of intra-coronary enhancement on diagnostic accuracy with 64-slice CT coronary angiography. Eur Radiol. 2008;18(3):576-83.

[8]Abbara S, Blanke P, Maroules CD, et al. SCCT guidelines for the performance and acquisition of coronary computed tomographic angiography: A report of the society of Cardiovascular Computed Tomography Guidelines Committee: Endorsed by the North American Society for Cardiovascular Imaging (NASCI). J Cardiovasc Comput Tomogr. 2016;10(6):435-449.

[9]Hirai N, Horiguchi J, Fujioka C, et al. Prospective versus retrospective ECG-gated 64-detector coronary CT angiography: assessment of image quality, stenosis, and radiation dose. Radiology. 2008;248(2):424-30.

[10]Söderberg M. Overview, practical tips and potential pitfalls of using automatic exposure control in ct: siemens care dose 4d. Radiat Prot Dosimetry. 2016;169(1-4):84-91.

[11]S, Blaha MJ, Kazerooni EA, Cury RC, et al. CAC-DRS: Coronary Artery Calcium Data and Reporting System. An expert consensus document of the Society of Cardiovascular Computed Tomography (SCCT). J Cardiovasc Comput Tomogr. 2018;12(3):185-191.

[12]Inoue Y, Itoh H, Nagahara K, Hata H, Mitsui K. Relationships of Radiation Dose Indices with Body Size Indices in Adult Body Computed Tomography. Tomography. 2023;9(4):1381-1392.

[13]Shi L, Dorbala S, Paez D, et al. INCAPS Investigators Group. Gender Differences in Radiation Dose From Nuclear Cardiology Studies Across the World: Findings From the INCAPS Registry. JACC Cardiovasc Imaging. 2016;9(4):376-84.

[14]Tiegs-Heiden CA, Murthy NS, Geske JR, e. Impact of flow pattern, body mass index, and age on intraprocedural fluoroscopic time and radiation dose during sacroiliac joint injections. Neuroradiol J. 2021;34(5):428-434.

[15]Inoue Y, Itoh H, Nagahara K, et al. Relationships of Radiation Dose Indices with Body Size Indices in Adult Body Computed Tomography. Tomography. 2023;9(4):1381-1392.

[16]Knuuti J, Wijns W, Saraste A, et al. ESC Scientific Document Group. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. Eur Heart J. 2020;41(3):407-477.

[17]Greffier J, Pereira F, Hamard A, et al. Effect of tin filter-based spectral shaping CT on image quality and radiation dose for routine use on ultralow-dose CT protocols: A phantom study. Diagn Interv Imaging. 2020;101(6):373-381.

[18]Tesche C, De Cecco CN, Vliegenthart R, et al. Accuracy and Radiation Dose Reduction Using Low-Voltage Computed Tomography Coronary Artery Calcium Scoring With Tin

Filtration. Am J Cardiol. 2017;119(4):675-680.

[19] Zhang T, Zhao S, Liu Y, et al. Comparison of two different GSI scanning protocols in head and neck CT angiography: Image quality and radiation dose. J Xray Sci Technol. 2022;30(4):689-696.

[20] Arfat M, Haq A, Beg T, et al. Optimization of CT radiation dose: Insight into DLP and CTDI. Future Health. 2024; 2:148.

[21] Menke J, Unterberg-Buchwald C, Staab W, et al. Head-to-head comparison of prospectively triggered vs retrospectively gated coronary computed tomography angiography: Meta-analysis of diagnostic accuracy, image quality, and radiation dose. Am Heart J. 2013;165(2):154-63.e3.

[22] Feng Q, Yin Y, Hua X, et al. Prospective ECG triggering versus low-dose retrospective ECG-gated 128-channel CT coronary angiography: comparison of image quality and radiation dose. Clin Radiol. 2010;65(10):809-14.

[23] Halliburton SS, Abbara S, Chen MY, et al. Society of Cardiovascular Computed Tomography. SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT. J Cardiovasc Comput Tomogr. 2011;5(4):198-224.

[24] Qin J, Liu LY, Fang Y, et al. 320-detector CT coronary angiography with prospective and retrospective electrocardiogram gating in a single heartbeat: comparison of image quality and radiation dose. Br J Radiol. 2012;85(1015):945-51.

[25] Huang B, Li J, Law MW, et al. Radiation dose and cancer risk in retrospectively and prospectively ECG-gated coronary angiography using 64-slice multidetector CT. Br J Radiol. 2010;83(986):152-8.

[26] Hausleiter J, Martinoff S, Hadamitzky M, et al. Image quality and radiation exposure with a low tube voltage protocol for coronary CT angiography results of the PROTECTION II Trial. JACC Cardiovasc Imaging. 2010;3(11):1113-23.

[27] Flohr TG, McCollough CH, Bruder H, et al. First performance evaluation of a dual-source CT (DSCT) system. Eur Radiol. 2006;16(2):256-68.

[28] Shen J, Du X, Guo D, et al. Prospective ECG-triggered coronary CT angiography: clinical value of noise-based tube current reduction method with iterative reconstruction. PLoS One. 2013;8(5):e65025.

[29] Stocker TJ, Deseive S, Leipsic J, et al. PROTECTION VI investigators. Reduction in radiation exposure in cardiovascular computed tomography imaging: results from the PROspective multicenter registry on radiaTion dose Estimates of cardiac CT angIOgraphy iN daily practice in 2017 (PROTECTION VI). Eur Heart J. 2018;39(41):3715-3723.

[30] Christner JA, Kofler JM, McCollough CH. Estimating effective dose for CT using dose-length product compared with using organ doses: consequences of adopting International Commission on Radiological Protection publication 103 or dual-energy scanning. AJR Am J Roentgenol. 2010;194(4):881-9.

[31] Halliburton SS, Abbara S, Chen MY, et al. Society of Cardiovascular Computed Tomography. SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT. J Cardiovasc Comput Tomogr. 2011;5(4):198-224.

[32] Grundy SM, Stone NJ, Bailey AL, et al. 2018 AHA/ACC/AACVPR/AAPA/ABC/ACPM/ADA/AGS/APhA/ASPC/NLA/PCNA Guideline on the Management of Blood

Cholesterol: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Circulation. 2019;139(25):e1046-e1081.

[33] Apfaltrer G, Albrecht MH, Schoepf UJ, et al. High-pitch low-voltage CT coronary artery calcium scoring with tin filtration: accuracy and radiation dose reduction. Eur Radiol. 2018 ;28(7):3097-3104.

[34] Soschynski M, Hagen F, Baumann S, et al. High Temporal Resolution Dual-Source Photon-Counting CT for Coronary Artery Disease: Initial Multicenter Clinical Experience. J Clin Med. 2022;11(20):6003.

[35] Inoue Y, Itoh H, Nagahara K, et al. Relationships of Radiation Dose Indices with Body Size Indices in Adult Body Computed Tomography. Tomography. 2023;9(4):1381-1392.

[36] Sabarudin A, Siong TW, Chin AW, et al. A comparison study of radiation effective dose in ECG-Gated Coronary CT Angiography and calcium scoring examinations performed with a dual-source CT scanner. Sci Rep. 2019;9(1):4374.

[37] Stocker TJ, Deseive S, Leipsic J, et al. PROTECTION VI investigators. Reduction in radiation exposure in cardiovascular computed tomography imaging: results from the PROspective multicenter registry on radiaTion dose Estimates of cardiac CT angIOgraphy iN daily practice in 2017 (PROTECTION VI). Eur Heart J. 2018;39(41):3715-3723.

[38] Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. JAMA. 2007;298(3):317-23.

[39] Maruyama T, Takada M, Hasuike T, et al. Radiation dose reduction and coronary assessability of prospective electrocardiogram-gated computed tomography coronary angiography: comparison with retrospective electrocardiogram-gated helical scan. J Am Coll Cardiol. 2008;52(18):1450-5.