Comparison of Radiation-Induced DNA Damage between Conventional and Computed Tomography Coronary Angiography

Gökhan Gökalp (gokhangokalp23@hotmail.com)
Gazi University Faculty of Medicine: Gazi Universitesi Tip Fakultesi
https://orcid.org/0000-0002-4958-7266

Serkan Ünlü
Gazi University Faculty of Medicine: Gazi Universitesi Tip Fakultesi

Aylin Elkama
Gazi University: Gazi Universitesi

Alican Yalçın
Gazi University Faculty of Medicine: Gazi Universitesi Tip Fakultesi

Mustafa Cemri
Gazi University Faculty of Medicine: Gazi Universitesi Tip Fakultesi

Bensu Karahalil
Gazi University Faculty of Medicine: Gazi Universitesi Tip Fakultesi

Gonca Erbaş
Gazi University Faculty of Medicine: Gazi Universitesi Tip Fakultesi

Nuri Bülent Boyacı
Gazi University Faculty of Medicine: Gazi Universitesi Tip Fakultesi

Research Article

Keywords: genotoxicity, conventional coronary angiography, coronary CT angiography, chromosome aberration test, ionizing radiation

DOI: https://doi.org/10.21203/rs.3.rs-249578/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License
Abstract

Purpose: Conventional coronary angiography (CCA) and coronary computed tomography angiography (CCTA) are the most frequently used imaging modalities to diagnose coronary artery disease (CAD). The amount of radiation and genotoxic damages of these imaging methods showed variation with the improved technology. Thus we sought to compare the ionizing radiation doses and radiation-induced DNA damage in patients who were performed CCA and CCTA.

Methods: 76 patients (39 in CCA group, 37 in CCTA group) were enrolled. Patients undergoing CCTA were grouped according to the use of ash technique (22 patients with CCTA-ash, 15 patients with CCTA-other). The effective radiation dose was recorded. Genotoxicity was compared with chromosome aberration test before and after imaging methods.

Results: There was a significant difference between the groups in effective radiation doses given to patients. Radiation was lowest in the CCTA-ash group, followed by CCA, and non-ash CCTA group. There was no change in chromosome aberration rate after CCTA-ash group (p = 0.479). There was a significant increase in chromosome aberration rates after CCA and CCTA-other groups (CCA: p = 0.001; CCTA-other: p = 0.01).

Conclusions: CTA which was taken with flash technique in dual-energy CT devices delivers lower dose radiation compared to other groups. Due to this significant difference, radiation-induced genetic damage was significantly less in patients with CCTA undergoing ash technique.

Introduction

Coronary artery disease (CAD) is the leading cause of morbidity and mortality in the world with an increasing prevalence regardless of the development status of the countries (1, 2). Although different modalities have been proposed for the diagnosis of coronary artery disease, conventional coronary angiography (CCA) and coronary computed tomography angiography (CCTA) are the tools commonly used for the diagnosis of CAD (3). CCA remains as the gold standard method for the diagnosis due to its high spatial and temporal resolution. However, it has several disadvantages such as need for hospitalization, risk of complications and high cost (4,5). However, CCTA is a noninvasive alternative, especially in the population with low and moderate risk of CAD (6,7). Recently novel developments in CCTA made it available to provide better anatomical details of coronary arteries by leading to useful information for the diagnosis of CAD (8,9). The commonality of both imaging methods is using ionizing radiation, which could have mutagenous effects (5,10). The radiation dose, which was previously reported to be higher in CCTA than CCA, decreased significantly with dual-energy technology (11). Using the flash technique an option presented in devices with recent technology, has also reduced the radiation dose to its minimum (11-13).

Ionizing radiation has many somatic and genetic effects on tissues. The increase in cancer risk, which is the most feared effect, has previously been demonstrated in observational studies, especially in people
exposed to radiation (14). The most important factor is DNA damage for the risk of cancer due to radiation exposure. There are several methods for detecting radiation-induced genotoxic damage. Chromosome aberration test (CAT) is a standard method commonly used to detect various structural chromosomal abnormalities induced by mutagens (15-17).

Thus, we sought to compare ionizing radiation doses of CCA and CCTA and radiation-induced DNA damage by chromosome aberration test caused by these imaging techniques.

**Methods**

**Study Population**

A total of 76 patients over 18 years, followed in XXX Cardiology Department and Radiology Departments were included. Thirty-nine patients underwent CCA and 37 patients underwent CCTA for diagnosis of CAD. Patients who had a history of malignancy, chemo-radiotherapy, coronary artery anomaly and radiological procedures other than chest radiography in the last year and patients with signs of active infection were excluded. In addition, since we aimed to compare CCTA with diagnostic CCA, patients who were performed ventriculography percutaneous coronary intervention in the same session were excluded. Before their participation, patients were informed about the research and written consents were obtained. This study was approved by the local ethical committee (XXX Faculty of Medicine Clinical Research Ethics Committee on 11.09.2017).

**Study Protocol**

Patients who were perfomed CCTA were divided into two groups according to being scanned with prospective ECG-triggered high-pitch spiral technique with dual-energy CT device (CT-flash). Thus, three patient groups were formed at last; CCA, CCTA-flash and CCTA-other. Baseline characteristics and effective radiation doses obtained from imaging tools were calculated and recorded. Blood samples were taken immediately before and one hour after imaging protocol.

**Conventional Coronary Angiography**

Conventional coronary angiography procedures were performed on the Innova IGS 320, General Electric Healthcare (Milwaukee, USA) device by physicians experienced in interventional cardiology. The number of images was left to the initiative of the interventional cardiologist, provided that all coronary imaging were performed (Figure 1).

**Coronary Computer Tomography Angiograph**

384 sections (192x2), dual energy, 3rd generation tomography device Somatom Force CT, Siemens Healthcare (Siemens AG, Erlangen, Germany) was used for CCTA. All patients had coronary calcium scoring before angiography procedure. No negative chronotropic agents were given to patients to reduce pre-procedure pulse. The imaging protocol was determined by the radiologist according to the pulse rate
of the patients during the procedure (Figure 2). Flash mode shooting (prospective ECG-triggered high-pitch spiral technique with dual-energy) was performed for eligible patients.

Radiation Dose Measurements

There are different parameters to calculate the radiation doses of the patients. In our study, we used the effective dose (ED) which is more frequently used among these parameters. The dose-area product (DAP) values of the patients who underwent CCA automatically measured by the device after the procedure and were converted to ED unit (mSv) by multiplying the converting factor for diagnostic CCA by 0.12 mSv / Gy.cm². In CCTA, the dose-length product (DLP) values given by the device were converted to ED by multiplying the conversion factor 0.014 mSv x (mGy x cm) -1 for the chest region.

Chromosome Aberration Test

CAT is a standard method commonly used to detect various structural and numerical chromosomal abnormalities induced by mutagens. Chromosome aberration frequency determined in circulating lymphocytes is a biomarker of cancer risk and reflects both early biological effects and individual sensitivity of exposure to genotoxic carcinogens (17). Chromosomal aberration analysis of human lymphocytes on metaphase is still accepted as the gold standard method for radiation biodosimeter (18). In our study, standard procedures were applied to the blood samples taken from patients before and after the imaging procedures for CAT. After lymphocytes were kept at the metaphase stage and spread to the slides, 100 metaphases were examined by experienced researchers for each individual (Figure 3). In our study, the structural aberration types, chromosome-chromatid gap, chromosome-chromatid fracture, ring chromosome, dicentric and acentric chromosomes were determined and total aberration rate was calculated before and after procedure for each patient. The relative change in chromosome aberration rates was accepted as the genotoxic effect of radiation.

Statistical Analysis

Statistical analyzes were performed using IBM SPSS (IBM, Chicago, IL, USA) for Windows Version 19.0 package program. Numerical variables were summarized with mean ± standard deviation or median [interquartile range]. Categorical variables were represented by numbers and percentages. The normality of numerical variables was examined by Shapiro Wilks test. The difference between the numerical values before and after imaging was examined by using T test in dependent groups in case of parametric test assumptions and Wilcoxon test in case of lack of parametric test assumptions. Differences between categorical variables were evaluated by chi-square test. Differences between groups were analyzed by one-way analysis of variance if parametric test assumptions were met, and Kruskal Walli’s test if parametric test assumptions were not met. Bonferroni correction was applied for post-hoc tests. Changes in the parameters of genetic damage assessment before and after imaging were calculated as a percentage. Significance level was accepted as p <0.05.

Results
Totally 76 patients were included in the study and CCA group consisted of 39 patients. The patients who underwent CCTA were divided into two groups according to the flash mode of the device. Of the 37 patients who underwent CCTA, 22 (59.5%) were in the CCTA-flash group and 15 (40.5%) were in the CCTA-other group. The baseline demographic and clinical characteristics of the participants are shown in Table 1. The mean age of the patients was 56.9 ± 10.8 years. Basal characteristics of the groups were similar except heart rate and age. The mean age of the CCTA-other group was higher compared to others.

The mean effective radiation dose given to all participants was 4.6 ± 2.9 mSv. The mean dose of radiation administered was significantly different between the groups (Figure 4). The highest radiation was observed in the CCTA-other group with an ED of 7.2 ± 2.4 mSv. The least radiation was seen in the CCTA-flash technique and the mean ED was 1.1 ± 0.2 mSv.

Total chromosome aberration rates measured by CAT before and after imaging methods are shown in Table 2. In the CCTA-flash group with the lowest radiation dose, there was no change in chromosome aberration rate after the study. Chromosome aberration rates increased significantly after imaging protocols for patients in the CCA and CCTA-other groups. The increase in these two groups was found to be similar (p = 0.366).

**Discussion**

In our study; we aimed to compare genotoxic damage due to ionizing radiation by assessing CAT in patients who underwent CCA and CCTA. Radiation dose was significantly lower in CCTA-flash group compared to other groups. While chromosomal aberration rate was not increased for CCTA-Flash group, chromosome aberrations were observed in CCTA-Other and CCA groups.

Coronary artery disease is one of the most important health problems worldwide due to its negative consequences and frequency (1,2,19). Although CCA still appears to be the gold standard in diagnosis; use of CCTA has increased considerably with the latest technological advances (10,20). There are two important reasons for this increase: firstly it provides very good anatomical detail in the visualization of coronary arteries with the increase in the number of sections with three-dimensional isometric imaging feature (8,9). Secondly high radiation doses previously feared in CT have been reduced by techniques in the new generation CT devices (11,21,34). The number of patients being scanned by CCA or CCTA is increasing due to higher admissions to hospitals with increased sensitivity to CAD. Moreover, access to mentioned imaging tools has become easier. This makes it more necessary to know the effects of ionizing radiation used in imaging method. Current guidelines emphasize that CCTA should be preferred for the diagnosis of CAD (22). However, adequate protocols should be followed to achieve low radiation doses to prevent radiation-induced comorbidities.

Radiation doses in CCA and CCTA have been compared many times and previous studies observed that patients are exposed to more radiation in CCTA (23,24). However, with the development of CT technology, especially with the emergence of dual energy CT systems, the radiation dose decreased in CCTA scans (25). Flash mode in dual-energy CCTA devices transmits low dose in a single pulse during a certain period
of the cardiac cycle (12,13,26). In our study, it was observed that the patients had very low dose of radiation, such as 1.1 ± 0.2 mSv, on flash mode. This result was found to be consistent with previous studies (12,27,33). In order to use flash mode in dual-energy CT devices, patients' heart rates should be low (28,29). Therefore, in our study, it is expected that the heart rates of patients with CCTA-flash group are lower than the other groups. The average ED calculated in the CCA group was found to be similar to previous studies (29).

Genotoxicity of ionizing radiation in CTA has been shown in several studies (30,31). However, there is a few studies comparing CCA and CCTA in this respect (5). Our study provided clinically important results by comparing two methods that expose radiation and whose prevalence is increasing day by day. Chromosomal damage has an important role as a biological indicator of genotoxic carcinogen exposure such as ionizing radiation. Determining the frequency of chromosomal aberration in cultured peripheral blood lymphocytes is one of the most widely used methods in evaluating the biological effects of genotoxic carcinogen exposure (32). In our study, we preferred the CAT because it shows genotoxicity effectively by being reliable for many years. There is no study comparing dual-energy CCTA and CCA using the CAT for the genotoxic effects of radiation.

Our results revealed that chromosome aberration increase was lowest in the CCTA-flash group, which has a significantly lower mean radiation dose received. However, the increase in chromosome aberration rate was not higher in CCTA-other group which has the the highest mean radiation dose received compared to CCA group (p = 0.366). It could be explained that the number of patients is not enough to provide a statistically significant difference and genotoxic effect may depend not only on radiation dose but also on individual sensitivity. Therefore larger prospective studies should be performed.

**Limitations of the Study**

The most important limitation of our study was the limited number of patients, however, we believe to explicit relevant results. Another limitation is that evaluation of chromosome aberration can be subjective. Therefore, it was evaluated by the only experienced researchers.

The results of this study indicate that coronary imaging with CCTA-flash mode in dual - produces less radiation and radiation-induced genotoxicity than non-flash mode CT scans and CCA. Further studies with a larger patient population are necessary to confirm the results of our study.

**Main Points**

- Coronary computed tomography angiography with flash mode in dual energy devices produces less radiation
- Coronary computed tomography angiography with flash mode in dual energy devices results less radiation induced genotoxicity assessed by chromosome aberration.
Conventional coronary angiography and coronary computed tomography angiography with non-flash mode result similar radiation-induced genotoxicity assessed by chromosome aberration.

Declarations

Funding
Not applicable

Conflicts of interest/Competing interests
All authors report no relationships that could be construed as a conflict of interest.

Ethics approval
The study was approved by the Gazi University Faculty of Medicine ethics committee.

Consent to participate
All subjects gave written informed consent prior to inclusion

Consent for publication
Not applicable

Availability of data and material
Data available on request due to privacy/ethical restrictions

Code availability
Not applicable

Authors' contributions
The listed authors contributed to the manuscript, in the following manner:
Conception and design of the study or analysis and interpretation of data, or both (GG, SÜ);
Manuscript drafting or critical revision for important intellectual content (GG, SÜ, AE, AY, BK);
Final approval of the manuscript submitted (SÜ, MC, GE, NBB)

References
1-Gao D, Ning N, Guo Y, Ning W, Niu X, Yang J. Computed tomography for detecting coronary artery plaques: a meta-analysis. Atherosclerosis. 2011; 219(2):603-609.

2-Roger VL, Go AS, Lloyd-Jones DM, Adams RJ, Berry JD, Brown TM, Carnethon MR, et al. Heart disease and stroke statistics–2011 update: a report from the American Heart Association. Circulation. 2011; 123(4):e18-e209.

3- Mangla A, Oliveros E, Williams KA, Kalra DK. Cardiac Imaging in the Diagnosis of Coronary Artery Disease. Curr Probl Cardiol 2017; 42(10):316-366.

4- Sun Z, Lin C, Davidson R, Dong C, Liao Y. Diagnostic value of 64-slice CT angiography in coronary artery disease: a systematic review. Eur J Radiol 2008; 67(1):78-84.

5- Sahinarslan A, Erbas G, Kocaman SA, Bas D, Akyel A, Karaer D, Ergün MA, et al. Comparison of radiation-induced damage between CT angiography and conventional coronary angiography. Acta Cardiol 2013; 68(3):291-297.

6- Taylor AJ, Cerqueira M, Hodgson JM, Mark D, Min J, O’Gara P, Rubin GD, et al. ACCF/SCCT/ACR/AHA/ASE/ASNC/NASCI/SCAI/SCMR 2010 appropriate use criteria for cardiac computed tomography. A report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the Society of Cardiovascular Computed Tomography, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the American Society of Nuclear Cardiology, the North American Society for Cardiovascular Imaging, the Society for Cardiovascular Angiography and Interventions, and the Society for Cardiovascular Magnetic Resonance. J Am Coll Cardiol 2010; 56(22):1864-1894.

7- Budoff MJ, Dowe D, Jollis JG, Gitter M, Sutherland J, Halamert E, Scherer M, 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):1724-1732.

8- Eren S, Bayram E, Fil F, Koplay M, Sirvanci M, Duran C, Sagsoz ME, et al. An investigation of the association between coronary artery dominance and coronary artery variations with coronary arterial disease by multidetector computed tomographic coronary angiography. J Comput Assist Tomogr 2008; 32(6):929-933.

9- Sun Z, Jiang W. Diagnostic value of multislice computed tomography angiography in coronary artery disease: a meta-analysis. Eur J Radiol 2006; 60(2):279-286.

10- Zhang JJ, Liu T, Feng Y, Wu WF, Mou CY, Zhai LH. Diagnostic Value of 64-Slice Dual-Source CT Coronary Angiography in Patients with Atrial Fibrillation: Comparison with Invasive Coronary Angiography. Korean J Radiol 2011; 12(4):416-423.
11- Achenbach S, Marwan M, Ropers D, Schepis T, Pflederer T, Anders K, Kuettner A, et al. Coronary computed tomography angiography with a consistent dose below 1 mSv using prospectively electrocardiogram-triggered high-pitch spiral acquisition. Eur Heart J 2010; 31(3):340-346.

12- Görmeli CA, Kahraman AS, Özdemir ZM, Yaşmur J, Özdemir R, Çolak NAC. Radiation dose comparison between prospectively ECG-triggered and retrospectively ECG-gated techniques of coronary computed tomography angiography on 256-slice dual source CT scanner. J Turgut Ozal Med Cent 2016; 23(2):181-184.

13- Sommer WH, Albrecht E, Bamberg F, Schenzle JC, Johnson TR, Neumaier K, Reiser MF, et al. Feasibility and radiation dose of high-pitch acquisition protocols in patients undergoing dual-source cardiac CT. AJR 2010; 195(6):1306-1312.

14- Cardis E, Vrijheid M, Blettner M, Gilbert E, Hakama M, Hill C, Howe G, et al. The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry: estimates of radiation-related cancer risks. Radiat Res 2007; 167(4):396-416.

15- Tucker JD. Sensitivity, specificity, and persistence of chromosome translocations for radiation biodosimetry. Military Medicine 2002; 167(2 Suppl):8-9.

16- Sekeroğlu ZA, Şekeroğlu V. Genetik toksisite testleri. TÜBAV Bilim Dergisi. 2011; 4(3):221-229.

17- Zeiger E. Identification of rodent carcinogens and noncarcinogens using genetic toxicity tests: premises, promises, and performance. Regul Toxicol Pharmacol 1998; 28(2):85-95.

18- Agrawala PK, Adhikari JS, Chaudhury NK. Lymphocyte chromosomal aberration assay in radiation biodosimetry. J Pharm Bioallied Sci 2010; 2(3):197-201.

19- Murray CJ, Lopez AD. Global mortality, disability, and the contribution of risk factors: Global Burden of Disease Study. Lancet 1997; 349(9063):1436-1442.

20- Kopp AF, Schroeder S, Kuettner A, Baumbach A, Georg C, Kuzo R, Heuschmid M, et al. Non-invasive coronary angiography with high resolution multidetector-row computed tomography. Results in 102 patients. Eur Heart J 2002; 23(21):1714-1725.

21- Nieman K, Rensing BJ, van Geuns RJ, Munne A, Ligthart JM, Pattynama PM, Krestin GP, et al. Usefulness of multislice computed tomography for detecting obstructive coronary artery disease. Am J Cardiol 2002; 89(8):913-918.

22- Knuuti J, Wijns W, Saraste A, Capodanno D, Barbato E, Funck-Brentano C, Prescott E, et al. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes: The Task Force for the diagnosis and management of chronic coronary syndromes of the European Society of Cardiology (ESC). Eur Heart J 2020; 41: 407-77.
23- Einstein AJ. Radiation Dose Reduction in Coronary CT Angiography. Time to Buckle Down. JACC: Cardiovascular Imaging 2015; 8(8):897-899.

24- Coles DR, Smail MA, Negus IS, Wilde P, Oberhoff M, Karsch KR, Baumbach A. Comparison of radiation doses from multislice computed tomography coronary angiography and conventional diagnostic angiography. J Am Coll Cardiol 2006; 47(9):1840-1845.

25- Popp HD, Meyer M, Brendel S, Prinzhorn W, Naumann N, Weiss C, Seifarth W, et al. Leukocyte DNA damage after reduced and conventional absorbed radiation doses using 3rd generation dual-source CT technology. Eur J Radiol Open 2016; 3:134-137.

26- Karcaaltincaba M, Aktas A. Dual-energy CT revisited with multidetector CT: review of principles and clinical applications. Diagn Interv Radiol 2011; 17(3):181-194.

27- Koplay M, Erdogan H, Avci A, Sivri M, Demir K, Guler I, Demir LS, et al. Radiation dose and diagnostic accuracy of high-pitch dual-source coronary angiography in the evaluation of coronary artery stenoses. Diagn Interv Imaging 2016; 97(4):461-469.

28- Smettei OA, Sayed S, M Al Habib A, Alharbi F, Abazid RM. Ultra-fast, low dose high-pitch (FLASH) versus prospectively-gated coronary computed tomography angiography: Comparison of image quality and patient radiation exposure. J Saudi Heart Assoc 2018; 30(3): 165–171.

29- Vijayalakshmi K, Kelly D, Chapple C- L, Williams D, Wright R, Stewart MJ, Hall JA, et al. Cardiac catheterisation: radiation doses and lifetime risk of malignancy. Heart 2007; 93(3):370-371.

30- Kuefner MA, Grudzenski S, Hamann J, Achenbach S, Lell M, Anders K, Schwab SA, et al. Effect of CT scan protocols on x-ray-induced DNA double-strand breaks in blood lymphocytes of patients undergoing coronary CT angiography. Eur Radiol 2010; 20(12):2917-2924.

31- Kuefner MA, Hinkmann FM, Alibek S, Azoulay S, Anders K, Kalender WA, Achenbach S, et al. Reduction of X-ray induced DNA double-strand breaks in blood lymphocytes during coronary CT angiography using high-pitch spiral data acquisition with prospective ECG-triggering. Invest Radiol 2010; 45(4):182-187.

32- Forni A. Comparison of chromosome aberrations and micronuclei in testing genotoxicity in humans. Toxicology Letters. 1994; 72(1-3):185-190.

33- Manna C, Silva M, Cobelli R, Poggesi S, Rossi C, Sverzellati N. High-pitch dual-source CT angiography without ECG-gating for imaging the whole aorta: intraindividual comparison with standard pitch single-source technique without ECG gating. Diagn Interv Radiol. 2017 ;23(4):293-299.

34- Yamasaki Y, Kamitani T, Sagiyama K, Matsuura Y, Hida T, Nagata H. Model-based iterative reconstruction for 320-detector row CT angiography reduces radiation exposure in infants with complex congenital heart disease. Diagn Interv Radiol 2021; 27(1):42-49.
Tables

Table 1. Baseline characteristics of the participants.
| Variables                  | Total (n = 76) | CCA (n = 39) | CCA-Flash (n=37) | CCA-Other (n=15) (n=22) | P  |
|---------------------------|----------------|--------------|------------------|--------------------------|----|
| Age (year)                | 56.9 ± 10.8    | 59.2 ± 11.1  | 54.5 ± 10.0      | 54 ± 9.5                 | 0.057 |
|                           |                |              | 50.3 ± 10.7      | 0.016                    |    |
| Gender (female)           | 31 (40.8%)     | 16 (%41)     | 15 (40.5%)       | 6 (27.3%)                | 0.460 |
|                           |                |              | 9 (60.0%)        | 0.138                    |    |
| SBP                       | 133.8 ± 12.9   | 135.1 ± 13.1 | 132.3 ± 12.7     | 133.2 ± 10.5             | 0.342 |
|                           |                |              | 131 ± 15.7       | 0.563                    |    |
| DBP                       | 80.7 ± 7.7     | 79.9 ± 7.8   | 81.5 ± 7.3       | 81.4 ± 6.9               | 0.363 |
|                           |                |              | 81.7 ± 8.6       | 0.658                    |    |
| HR                        | 71.6 ± 10.1    | 72.7 ± 10.4* | 70.3 ± 9.75      | 63 ± 2.8*                | 0.304 |
|                           |                |              | 81.1 ± 4.9       | <0.001                   |    |
| Length (cm)               | 167 ± 10.4     | 167 ± 10.4   | 166.3 ± 8.1      | 168 ± 8.1                | 0.770 |
|                           |                |              | 164 ± 8.0        | 0.455                    |    |
| Weight (kg)               | 77.7 ± 13.9    | 76.9 ± 15.6  | 78.5 ± 12.1      | 80.6 ± 12.4              | 0.610 |
|                           |                |              | 75.5 ± 11.3      | 0.493                    |    |
| BMI (kg/m^2)              | 28.2 ± 4.3     | 27.5 ± 4.2   | 28.8 ± 4.4       | 28.9 ± 4                 | 0.182 |
|                           |                |              | 28.8 ± 5.1       | 0.413                    |    |
| Diabetes mellitus         | 18 (23.7%)     | 13 (33.3%)   | 5 (13.6%)        | 3 (13.6%)                | 0.059 |
|                           |                |              | 2 (13.3%)        | 0.127                    |    |
| Hypertension              | 36 (47.4%)     | 21 (53.8%)   | 15 (40.5%)       | 9 (40.9%)                | 0.262 |
|                           |                |              | 6 (40%)          | 0.508                    |    |
| Hyperlipidemia            | 29 (38.2%)     | 18 (46.5%)   | 11(29.7%)        | 8 (36.4%)                | 0.163 |
|                           |                |              | 3 (20%)          | 0.204                    |    |
| Smoking                   | 42 (55.3%)     | 21 (53.8%)   | 13 (59.1%)       | 8 (53.3%)                | 0.104 |
|                           |                |              |                  | 0.104                    |    |
| Alcohol                   | 9 (24.3%)      |              |                  |                         | 0.821 |
Table 2. Total chromosome aberration rates before and after imaging.

| Groups      | Total C. Aberration Rate (%) – Before | Total C. Aberration Rate (%) – After | P    |
|-------------|---------------------------------------|--------------------------------------|------|
| CCA         | 4.3 ± 2.9                             | 5.3 ± 2.9                            | 0.001|
| CCTA – Flash| 3.4 ± 2.4                             | 3.2 ± 2.3                            | 0.479|
| CCTA – Other| 3.1 ± 2.4                             | 4.7 ± 2.6                            | 0.010|

BMI: Body mass index, CCA: Conventional Coronary Angiography, CCTA: Coronary Computed Tomography Angiography, CKD: Chronic kidney disease, DBP: Diastolic blood pressure, HR: Heart rate, SBP: Systolic blood pressure

CCA: conventional coronary angiography, CCTA; coronary computer tomography angiography

Figures
Figure 1

Conventional coronary angiography image of a study patient.
Figure 2

Coronary computed tomography angiography image of a study patient.
Figure 3

Chromosome aberration test of lymphocyte chromosomes at the metaphase stage with light microscopy.

| Relative Difference (%) | CCA | CCTA-Flash | CCTA-Other |
|-------------------------|-----|------------|------------|
|                         |     |            |            |
|                         | 0   | 50         | 100        |
|                         | 50  | 150        | 200        |
|                         | 100 | 250        |            |

P-values:
- P = 0.366
- P = 0.021
- P = 0.036
Figure 4

Comparison of mean effective radiation dose among study groups. (P<0.001 with ANOVA, p values regarding post-hoc tests were presented on the bars) (CCA; conventional coronary angiography, CCTA-Flash; coronary computed tomographic angiography-flash, CCTA-Other; coronary computed tomographic angiography-other groups)