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Analysis of coronary artery anomalies and variants in cardiac risk groups through coronary computed tomography angiography

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Abstract

Aim: The purpose of this study is to investigate prevalance of coronary artery anomalies and variants in a cardiac risk group by using coronary computed tomography (CT) angiography.

Materials and Methods: Coronary CT angiography scans were retrieved for 527 consecutive adult patients (265 male, 262 female) with a preliminary diagnosis or suspicion of coronary artery disease between 2021 and 2023. Coronary artery anomalies and vascular variants were retrospectively reviewed.

Results: The study revealed that 85.97% had right dominant coronary circulation, 22.39% had myocardial bridging, and 9.3% having a ramus intermedius artery. Among the identified coronary anomalies, anomalies of origination and course were the leading causes (3.6 %), except for hypoplasia, which had a prevalence of 6.07 %. Overall, no significant relationships were found between gender or coronary artery disease and the frequency of coronary artery anomalies.

Conclusion: Coronary artery anomalies and variants, which are mostly asymptomatic, represent a broad spectrum of entities that can be accurately diagnosed by coronary CT angiography.

Introduction

The coronary arteries are the main vessels supplying blood to the myocardium of the heart [1]. The left main coronary artery (LMCA) typically arises from the left coronary sinus, while the right coronary artery (RCA) regularly originates from the right coronary sinus and courses through the right atrioventricular groove [1,2]. The LMCA bifurcates into the left anterior descending (LAD) artery and left circumflex (LCx) artery [2,3].While the LAD gives rise to diagonal branches, the LCx gives rise to obtuse marginal branches, and the RCA gives rise to the conus artery, acute marginal branches and the posterior descending artery (PDA) in right dominant coronary circulation [1-3]. Coronary arteries, which usually follow a specific pattern, may sometimes exhibit variations or anomalies [4]. Coronary artery variations are often incidental findings during imaging and considered benign. In contrast, coronary artery anomalies, though rarer, they can cause decreased blood flow to the myocardium and lead to angina, arrhythmias, and even sudden cardiac arrest [5]. Coronary artery variations and anomalies can be diagnosed using various imaging methods such as conventional coronary angiography, cardiac computed tomography (CT), and magnetic resonance imaging (MRI) [6]. Whether treatment is required depends on the type of anomaly, the patient's symptoms, and clinical evaluations. In some cases, surgical intervention may be necessary, while in other cases, only monitoring and symptom management may be required [7-9]. In this study, we aimed to demonstrate the coronary artery anomalies and variants in cardiac risk groups (defined as the presence of one or more cardiovascular risk factors, including high blood pressure, high cholesterol, smoking, diabetes mellitus, obesity, or a family history of cardiovascular disease) using cardiac CT imaging.

Materials and Methods

This retrospective study is approved by the Institutional Review Board of the Bolu Abant İzzet Baysal University (Project decision number: 2023/332). Given the retrospective setting, informed consent was waived by the committee. This research study followed the Declaration of Helsinki and adhered to the STROBE guidelines for reporting [10].

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Study design and population

Based on the reported prevalence of coronary artery anomalies and variations, the sample size was calculated to be 185 patients, using a significance level (α) of 0.05 and a confidence interval of 95%. Cardiac CT examinations of 627 consecutive adult patients with a preliminary diagnosis or suspicion of coronary artery disease from January 2021 to December 2023 were retrospectively reviewed. Patients aged 18 years or older, with at least one cardiovascular risk factor (including high blood pressure, high cholesterol, smoking, diabetes mellitus, obesity, or a family history of cardiovascular disease), and who underwent coronary CT angiography for clinical indications during the study period were included. Patients with high heart rates resulting in nondiagnostic images (N=38), high coronary artery calcium score (Agatston score greater than 400, N=34), those who had only non-enhanced calcium score images (N=22), undergone prior coronary revascularization (N=6) were excluded from the study. A history of allergic reactions to iodine contrast medium, renal failure, or pregnancy was considered contraindications for cardiac contrast enhanced computed tomography. Figure 1 presents a flowchart summarizing the data collection procedure. The main indications for cardiac CT were typical or atypical chest pain, screening for coronary artery disease and determination of the patency of stents. One of the patients was referred from the emergency department, one from interventional radiology, one from neurology, one from internal medicine, two from the coronary intensive care unit, six from the cardiovascular surgery outpatient clinic, and 515 from the cardiology outpatient clinic for cardiac CT imaging.

The primary endpoint of this study was the prevalence of coronary artery anomalies and variants identified through coronary computed tomography (CT) angiography.

Patient preparation

Patients are asked not to eat four hours prior to scan and they should avoid caffeinated drinks and smoking on the day of examination. Administering a beta-blocker (up to a total dose of 20 mg metoprolol) as premedication on the study day may help lower the heart rate and reduce waiting times. An intravenous (IV) line should be inserted in the right antecubital vein or forearm using an 18-20 gauge catheter.

Cardiac CT imaging protocol and image acquisition

All CT images were acquired using a 64-slice scanner (Revolution Evo, GE Healthcare, Milwaukee, Wisconsin, United States). The patient is kept in supine position, electrocardiography (ECG) electrodes are placed on the anterior chest wall, and moved into the scanner feet first with legs flat and both arms above their head on the table. When starting the imaging, first a scout image is obtained to determine the boundaries of the heart. In order to perform calcium scoring in patients between the ages of 40-70, non-contrast images are acquired from the level of tracheal bifurcation to the inferior border of the heart [11]. Depending on the patient's heart rate, prospective axial (if the patient's heart rate less than 70) or retrospective helical scanning was done with single breath hold and image acquisition starting from the tracheal bifurcation till 1 cm below diaphragm. A biphasic injection protocol with bolus tracking was used, starting with 70-90 mL of non-ionic contrast medium (iohexol 350 mgI/mL) at 5-6 mL/s, followed by a 30 mL saline chaser at the same flow rate. Saline chaser bolus was used to flush the contrast from the right side of the heart. The threshold for initiating image acquisition is set at 200 HU in the descending aorta. The procedure approximately takes 15-20 minutes.

Image reconstruction and interpretation

Cardiac CT scans were processed using multiplanar reconstruction (MPR) and 3-dimensional volume rendering (3D VR) techniques on a workstation (cardIQ Xpress software, Advantage Workstation 4.3, GE Healthcare, Milwaukee, WI, USA). Two experienced cardiovascular radiologists independently assessed the scans, and the final diagnoses were determined by consensus. Coronary artery anomalies are classified based on a system modified from the Angelini classification as follows: 1. Anomalies of origination and course, 2. Intrinsic anomalies; 3. Anomalies of termination [7,12,13].

Statistical analysis

All statistical analyses were performed using SPSS 24.0 software (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was used to test normality of data. Categorical variables were expressed as number and percentage, while numerical variables were expressed by mean ± SD, or median and interquartile range according to distribution of data. The relationships between gender and the frequency of coronary artery anomalies, as well as between coronary artery disease and the frequency of coronary artery anomalies, were evaluated using the chi-square test. An independent samples t-test was used to compare the calcium scores of individuals with and without a ramus intermedius (RIM). A p-value less than 0.05 was considered statistically significant.

Results

This study was conducted on eligible 527 patients in the period from January 2021 to December 2023. The mean age of the participants was 49.36 years with a standard

Table 1. Baseline demographics and clinical characteristics of the study population.

Characteristic, n=527	
Mean age (years)	49.36 ± 11.98
Age min-max (years)	19-85
Male, n (%)	265 (50.3%)
Female, n (%)	262 (49.7%)
Patients with calcium score scans, n (%)	293 (55.6%)
Calcium score, median (IQR)	0 (47)
Calcium score, min-max	0-393

Min: minimum, max: maximum, n: number, IQR: Interquartile range.

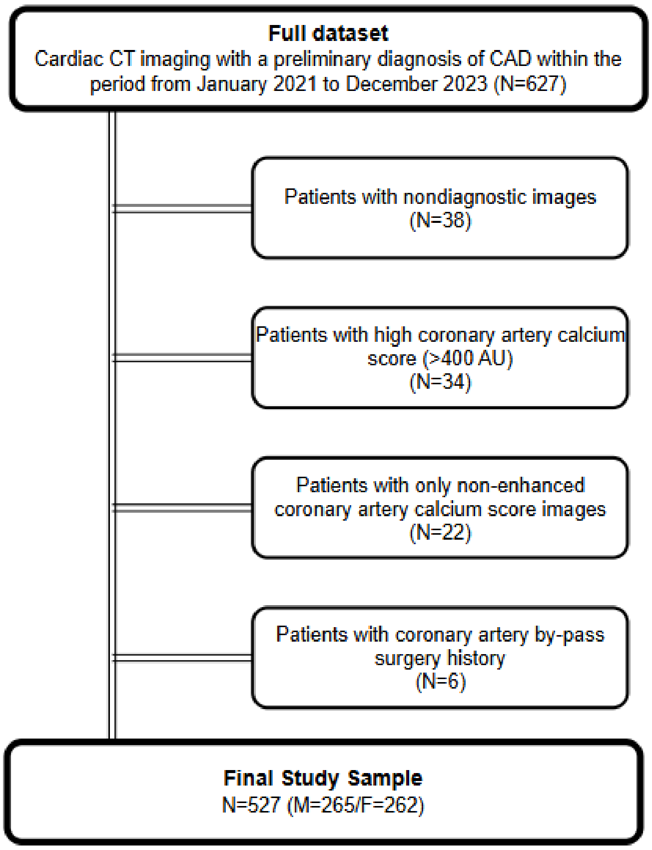

Figure 1. Flowchart of the study.

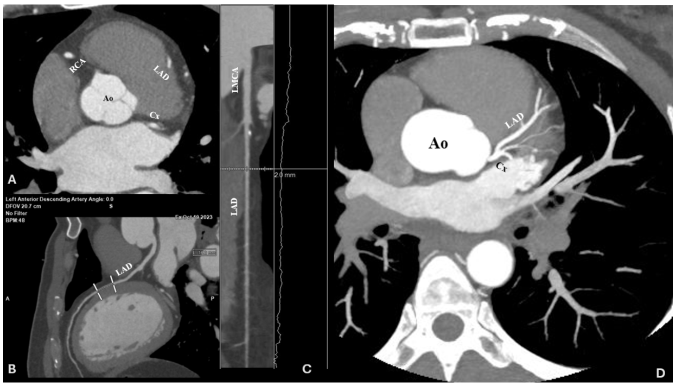

Figure 2. 49 year-old male patient with superficial myocardial bridging of left anterior descending (LAD). Axial computed tomography slice (A), and multiplanar reformat (MPR) images are presented (B, C). A 43-year-old female patient has a ramus intermedius branch (RIM) (D). Maximum intensity projection (MIP) images from the axial computed tomography scan are provided. Ao: Aorta, LMCA: Left main coronary artery, LAD: Left anterior descending artery, RCA: Right coronary artery, RIM: Ramus intermedius, LCx: Left circumflex artery.

deviation of 11.98 years, ranging from 19 to 85 years. The study population consisted of 265 males (50.3%), and 262 females (49.7%). Only 293 participants (55.6%) also had coronary artery calcium score scans, and the median calcium score value was 0 and interquartile range was 47. The baseline demographics and clinical characteristics of the study population are summarized in Table 1. The chi-square test revealed no statistically significant relationship between gender and the frequency of coronary artery anomalies ($p = 0.869$), nor between coronary artery disease and the frequency of coronary artery anomalies ($p = 0.87$). Additionally, no statistically significant difference was observed between patients with and without a ramus intermedius in terms of coronary calcium score ($p=0.472$).

Normal variants

Of the coronary artery circulation, 453 cases (85.97%) were right dominant, 71 cases (13.47%) were left dominant, and 3 cases (0.57%) were co-dominant. Myocardial bridging

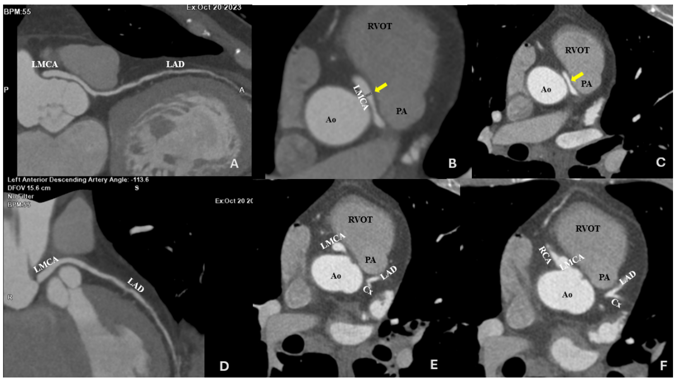

Figure 3. A 41-year-old male patient has an interarterial course of the left main coronary artery (LMCA), which originates from the right coronary sinus of Valsalva. Curved multiplanar reformat (MPR) images (A, D) and axial computed tomography images (B, C, E, and F) are presented. Ao: Aorta, LMCA: Left main coronary artery, LAD: Left anterior descending artery, Cx: Circumflex artery, RCA: Right coronary artery, PA: Pulmonary artery, RVOT: Right ventricular outflow tract.

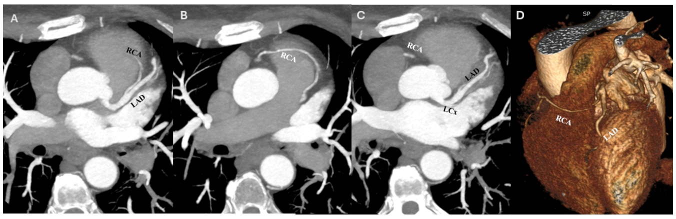

Figure 4. A 70-year-old female patient with a Lipton-Yamanaka class LIIA-V2 single coronary artery is shown in maximum intensity projection images (A, B, and C) and a three-dimensional virtual reality (3D VR) image (D). All coronary arteries arise from the left coronary sinus, while the right coronary artery exhibits a prepulmonic course. LAD: Left anterior descending artery, LCx: Left circumflex artery, RCA: Right coronary artery.

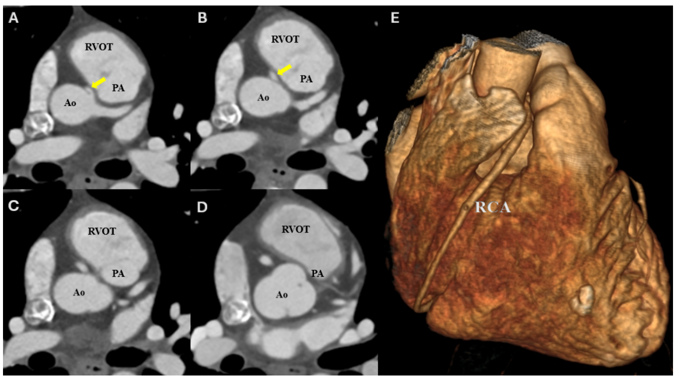

Figure 5. A 19-year-old male patient has a malignant interarterial course of the right coronary artery. Images A, B, C, and D are axial CT slices, while image E is a three-dimensional virtual reality (3D VR) image. Ao: Aorta, RCA: Right coronary artery, PA: Pulmonary artery, RVOT: Right ventricular outflow tract.

Table 2. The prevalance of coronary artery variants.

Dominancy	
Right coronary dominancy, n(%)	453 (85.97%)
Left coronary dominancy, n(%)	71 (13.47%)
Co-dominant coronary circulation, n(%)	3 (0.57%)
Myocardial bridging	
Deep myocardial bridging, n(%)	2 (0.4%)
Superficial myocardial bridging, n(%)	116 (22.01%)
Ramus intermedius artery, n(%)	49 (9.3%)
Short LMCA	11 (2.09%)
Acute take-off coronary arteries	8 (1.5%)
Separate origin of conus branch	6 (1.14 %)

LMCA: left main coronary artery, n: number.

was observed in 118 cases (22.39%), with 2 (0.4%) classified as deep (≥2 mm depth of overlying myocardium) and 116 (22.01%) as superficial (less than 2 mm depth of overlying myocardium) (Figure 2A,B,C). A ramus intermedius artery resulting from trifurcation of left main coronary artery (LMCA) was identified in 49 (9.3%) participants (Figure 2D). In 11 cases (2.09%), a short LMCA (less than 5 mm) was detected. Additionally, acute take-off of coronary arteries was noted in eight cases (1.5%), with two cases (0.38%) involving the right coronary artery (RCA) and six cases (1.14%) involving the LMCA. Separate origins of the conus branch were observed in six cases (1.14%), with the conus artery arising directly from the aorta in four cases (0.76%), and from the left circumflex artery (LCx) in two cases (0.38%) (See Table 2).

Coronary anomalies

Anomalies of origination and course

Ectopic coronary origin from the contralateral coronary sinus

We identified the left coronary artery originating from the right coronary sinus in one case (0.19%) (Figure 3). A circumflex artery originating from the right coronary sinus was found in two cases (0.38%). There was one case (0.19%) of a single coronary artery (Figure 4). The RCA originating from the LCx was detected in one case (0.19%). We also observed one case (0.19%) where the circumflex artery originated from the RCA. Finally, a circumflex artery originating from the diagonal branch of LAD was noted in one case (0.19%). Additionally, in one case (0.19%), an anomalous obtuse marginal branch was observed originating from the RCA, rather than its typical origin from the LCx.

Absence of the left coronary trunk

Among the 527 cases examined, four cases (0.76%) exhibited the absence of the left coronary trunk, and LAD and LCx were found to be separated from left sinus valsalva.

Anomalous course of coronary arteries

The interarterial course of the RCA, also known as a malignant course, was observed in five cases (0.94%), where the artery had an aberrant origin from the left coronary sinus (Figure 5). In contrast, the interarterial course of the LMCA, where the LMCA originates from the right coronary sinus, was noted in two cases (0.38%).

Anomalous location of the coronary ostium

Among all participants, only one case (0.19%) exhibited high take-off of the RCA.

Intrinsic anomalies

Ectasia or aneurysm

Among all participants, only one case (0.19%) exhibited RCA ectasia.

Hypoplasia or agenesis

We observed a thin left main coronary artery (LM) in one case (0.19%), hypoplasia of the RCA was detected in 13 cases (2.46%), and hypoplasia of the circumflex artery was found in 17 cases (3.22%).

Anomalous origin of the posterior descending artery

In one case (0.19%), the posterior descending artery (PDA) was observed originating from the acute marginal branch.

Anomalies of termination

Fistula

Anomalies of coronary termination were identified in two cases (0.38%). One case (0.19%) involved a fistula between the RCA and the coronary sinus, while another case (0.19%) involved a fistula between the LAD and the pulmonary trunk.

All types of coronary artery anomalies detected in our study are summarized in Table 3.

Discussion

Coronary CT angiography allows for the non-invasive visualization of coronary vascular structures, reduces the cost and risks associated with conventional angiography, and has thus become the diagnostic test of choice for investigating coronary artery disease [14]. With the increasing use of coronary CT angiography in daily practice, the incidental detection of coronary artery anomalies and variations has become easier. While most of the cases are asymptomatic, some of the patients may experience chest pain, congestive heart failure, and in rare instances, sudden cardiac death [15].

Coronary dominance is determined by the coronary artery branch that gives rise to the PDA: if the PDA originates from the RCA, it is classified as right dominant; if it originates from the left LCx, it is classified as left dominant; and if it arises from both, it is classified as codominant [16]. The clinical importance of coronary dominance lies in its implications for the preparation of bypass surgery and the potential outcomes [17]. Approximately 70-80 % of the population exhibits right coronary dominance, 5-10 % exhibits left coronary dominance, and the remaining 10-20 % demonstrates codominance [17]. The results of

Table 3. The prevalance of coronary artery anomalies.

1. Anomalies of Origination and Course	Cases n (%)
1.1 Ectopic coronary origin from the contralateral coronary sinus	1 (0.19%)
Left coronary artery originating from the right coronary sinus	2 (0.38%)
Circumflex artery originating from the right coronary sinus	1 (0.19%)
Single Coronary artery	1 (0.19%)
Right coronary artery originating from the circumflex artery	1 (0.19%)
Circumflex artery originating from the right coronary artery	1 (0.19%)
Circumflex artery originating from diagonal branch	1 (0.19%)
Obtuse marginal branch from right coronary artery	1 (0.19%)
1.2.Absence of left coronary trunk	4 (0.76%)
1.3. Anomalous course of coronary arteries	
Interarterial course of right coronary artery	5 (0.94%)
Interarterial course of left main coronary artery	2 (0.38%)
2. Anomalous location of the coronary ostium	
High take-off of the right coronary artery	1 (0.19%)
3. Intrinsic anomalies	
3.1. Ectasia or Aneurysm	
Right coronary artery ectasia	1 (0.19%)
3.2. Hypoplasia or Agenesis	
Thin left main coronary artery	1 (0.19%)
Hypoplasia of right coronary artery	13 (2.46%)
Hypoplasia of circumflex artery	17 (3.22%)
3.3. Anomalous origin of the posterior descending artery	
Posterior descending artery from acute marginal branch	1 (0.19%)
4. Anomalies of termination	
4.1.Fistula	
Fistula between right coronary artery and coronary sinus	
Fistula between left anterior descending artery and pulmonary trunk	

n: number.

our study revealed a higher prevalence of right and left coronary dominance, while the incidence of codominance was lower than expected. The discrepancy in the dominance pattern can be attributed to the characteristics of the study cohort. Additionally, if the PDA originates from the LAD, it is referred to as "superdominant", which is an extremely rare condition with a clinical significance, potentially leading to larger infarct, higher morbidity-mortality [18]. In our study group, there was only one case (0.19%) of superdominant LAD.

A myocardial bridge can be defined as a condition in which coronary arteries course through myocardium rather than over the epicardium [19]. The part of the coronary artery encased within the myocardium is referred to as a 'tunneled artery,' while the enveloping muscle is termed the 'bridge' [20]. Myocardial bridging is divided into two groups based on its depth: superficial and deep. If the depth is less than 2 mm, it is considered superficial, and if it is 2 mm or more, it is referred to as deep myocardial bridging [20]. There is ongoing debate regarding myocardial bridging, specifically whether it should be classified as a congenital anomaly or a normal anatomical variant [5,14,21]. In the current study, we classified myocardial bridging as an anatomical variant because anatomical features of the coronary arteries should be considered variants rather than congenital anomalies when they occur in more than 1% of the general population [21-23]. We encountered 120 cases (22.8%) of myocardial bridging in this study, the majority of which were located superficially. Most patients with myocardial bridges are asymptomatic; however, some may experience symptoms such as angina, palpitations, myocardial ischemia, paroxysmal atrioventricular block, ventricular tachycardia, or sudden cardiac death [24]. On some occasions, the LMCA trifurcates and gives rise to the LAD, LCx, and ramus intermedius branch. There is controversial evidence regarding the increased risk of atherosclerosis or potential improvement in survival [25]. In our study, 9.3% of participants had a ramus intermedius branch, and their calcium scores were relatively higher compared to those without, though the difference was not statistically significant. Given the observed nonsignificant difference in means, further research is necessary to elucidate this trend towards higher values in patients with ramus intermedius branch.

Normal length of the LMCA varies from 2 to 40 mm according to an autopsy study [26,27]. A length of the LMCA less than 5 mm is considered a short LMCA, which is a normal variant [28]. In our study there are 11 cases (2.09%) with short LMCA, slightly less than previously reported [29,30]. There is a debate regarding the association between a short left main coronary artery (LMCA) and an increased risk of atherosclerosis, with studies reporting conflicting results [31,32]. Acute take-off of a coronary artery is another variant, which can be described as a sharp angle (less than 45 degree) between coronary artery and the aorta. This may lead to difficulty during coronary interventions [33].

There is no single standard approach regarding coronary artery anomalies classification, however most of the authors support anatomy based perspective to classify coronary artery anomalies [9,34-38]. The reported prevalence of coronary artery anomalies shows great variability [16]. In the current study, we used a classification system adapted from Angelini classification [12,13]. The most common anomalies were intrinsic anomalies (6.07 %) especially hypoplasia or agenesis followed by anomalies of origin and course (3.6 %). There is a need for a more consolidated approach to better describe and appreciate the clinical impact of coronary artery anomalies.

Limitations

The main limitations of this study are the relatively small number of the study group, absence of coronary catheter angiography images, and referral bias.

Conclusion

In conclusion, coronary artery anomalies and variations encompass a wide spectrum of abnormalities in coronary circulation. Most of these do not cause any symptoms, but some can lead to serious heart problems, including sudden cardiac death. Treatment is personalized based on the patient's condition and symptoms; therefore, an accurate diagnosis is crucial and can be achieved through coronary CT angiography.

Conflicts of interest

The authors declare that they have no conflict of interest. All authors have actively participated in this manuscript and approved the final article.

IRB statement

This study was performed in accordance with the Declaration of Helsinki and the institutional committee has approved the prospective design of the study.

Ethical approval

This study has been approved by the Clinical Research Ethics Committee of Bolu Abant İzzet Baysal University Decision No: 2023/332, dated November 7, 2023.

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