Assessment of the left coronary artery bifurcation angle as a coronary artery disease risk factor and its impact on coronary artery calcification

Ömer Can Kızılay[1], Cem Kopuz[1], Mehmet Korkmaz[2], Hüseyin Gökhan Yavaş[2]

[1] Department of Anatomy, Faculty of Medicine, Kütahya Health Sciences University, Kütahya, Turkey

[2] Department of Radiology, Faculty of Medicine, Kütahya Health Sciences University, Kütahya, Turkey

SUMMARY

Coronary artery calcification (CAC) is a recognized marker of atherosclerosis and cardiovascular risk. While age and sex are established risk factors, the influence of coronary bifurcation angles (left anterior descending artery – LAD, left main artery – LMA, left circumflex artery – LCx) on CAC remains unclear. This study aimed to investigate the relationship between these anatomical angles, demographic factors, and CAC presence/severity. This retrospective cross-sectional study included 164 patients over 18 years of age who underwent coronary computed tomography angiography (CCTA) between April 2024 and October 2024. Ethical approval was obtained, and data were anonymized. Patients with prior interventions, anatomical variations, or poor image quality were excluded. Computed tomography (CT) images were obtained using a 128-slice scanner. Bifurcation angles were measured on 3D reconstructions. CAC was evaluated using non-contrast CT and the Agatston scoring method. Statistical and ROC analyses were performed to assess associations between variables.

CAC was more common in older and male patients ($p < 0.05$). Bifurcation angles, including LAD–LCx, showed no significant association with the presence or severity of CAC ($p > 0.05$; AUC values < 0.60). No significant correlation was found between angles and calcium scores. Age and male sex were strongly associated with CAC, supporting known risk patterns. LAD was the most frequently calcified vessel. Although bifurcation angles did not show significant predictive value, geometric trends suggest a potential hemodynamic role in early atherosclerosis. Male sex and age are significant predictors of CAC. While bifurcation angles were not independently predictive, their anatomical influence warrants further investigation, particularly regarding LAD involvement.

Key words: Coronary artery calcification – Bifurcation angle – Computed tomography – Angiography

INTRODUCTION

Coronary heart disease is one of the main causes of death in developed and developing countries (Lopez et al., 2006). Therefore, investigating the factors that may cause coronary artery disease (CAD) and initiating preventive treatments early

Corresponding author:
Ömer Can Kizilay. Department of Anatomy, Faculty of Medicine, Kütahya Health Sciences University, Kütahya, Turkey. E-mail: omercan.kizilay@ksbu.edu.tr

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for patients in the high-risk group are becoming increasingly essential. According to this point of view, numerous researchers investigate the hemodynamics of coronary arteries, as well as the implications of alterations in these hemodynamics on CAD (Chaichana et al., 2011; Markl et al., 2010). It is established that the bifurcation angle of the left coronary artery causes a change in the hemodynamics along the bifurcation area. This means that the wall shear stresses on the outer wall of the vessels in this region are lower than the wall shear stresses on the inner wall, which poses a risk to vascular integrity (Chaichana et al., 2011; Cheng et al., 2006; Malek et al., 1999). The advancement of technology has made it possible for coronary angiography to be performed with computed tomography (CT) in a non-invasive manner. This method measures the bifurcation angle with a high degree of precision, and it is frequently utilized by clinicians for the purpose of diagnosing coronary diseases (Sun et al., 2013). Computed tomography-assisted angiography is also gaining importance, since it allows clinicians to grade calcified plaques that have already developed (Cui et al., 2017).

Our study's major hypothesis is that individuals with a large left coronary artery bifurcation angle will have CAD more frequently than those with a small left coronary artery bifurcation angle, because it will be more difficult to maintain vascular integrity among these patients. One of our secondary hypotheses is that patients with a high left coronary artery bifurcation angle tend to be male and older, both established risk factors for CAD, and that this anatomical configuration may predispose to a higher calcification burden, particularly in the left anterior descending artery (LAD). Our other secondary hypothesis is that as the left coronary artery bifurcation angle increases, the calcium scoring of the expected plaques will also increase. Finally, in our study, in addition to the angle of the left coronary artery bifurcation, the angle between the left coronary artery (LMA) and the ramus interventricularis anterior (LAD) and the angle between the LMA and the ramus circumflexus (LCx) will be taken into consideration, and it will be evaluated whether these two additional angles have an effect on CAD. To evaluate the hypotheses of our study, computed tomography-guided angiography was deemed appropriate as its advantages have been previously mentioned.

CASE REPORT

All procedures performed in this study were carried out in accordance with the ethical standards of the Kütahya Health Sciences University Non-Interventional Clinical Research Ethics Committee (Decision no: 2024/13-11) and with the 1964 Helsinki Declaration and its later amendments. This retrospective study was conducted using anonymized data obtained from hospital records and imaging archives, with no direct patient contact. Informed consent was waived by the Ethics Committee due to the retrospective and non-interventional nature of the study.

Angiography images of patients over the age of 18 who underwent computed tomography-guided coronary angiography at the Department of Radiology at Kütahya Evliya Çelebi Training and Research Hospital between April 2024 to October 2024 were retrospectively examined. After intravenous administration of 60 ml of non-ionic contrast agent, images were obtained in the axial plane with a GE Revolution EVO 128-slice computed tomography (GE MEDICAL SYSTEMS) at a slice thickness of 0.625 mm. Retrospective ECG triggering was used during imaging. Original data in digital imaging and communications in medicine (DICOM) format were loaded into a workstation equipped with the GE CardiQ Express Elite program (GE MEDICAL SYSTEMS) for the creation of two-dimensional and three-dimensional images.

The study excluded patients with cardiac stents, valves, pacemakers, and similar implants; those who had previously undergone coronary artery surgery; those with a history of malignancies; those who were pregnant at the time of imaging; and those whose procedure-related images were insufficient for the measurements the study intended for.

Additionally, patients with anterior or posterior tilt of the LMA, or with high or low origination of the LMA identified on the reviewed images, were also excluded. Furthermore, patients with a ramus intermedius, left coronary artery dominance, or a slender circumflex artery (slender LCx) were not included in the study. A total of 164 patients from the Western Anatolia region were found to be eligible for inclusion in this study. Images were de-identified for analysis once the eligible patients' age, sex, and body mass index information had been recorded.

Multiplanar reconstruction was performed exactly in the plane of LMA, LAD and LCx vessels at the left coronary bifurcation. The bifurcation angle of the left coronary artery is defined as the angle formed between the centerline of LAD and LCx in volume rendering images. Additional angles measured using the same methodology included the angle between the LMA and LAD, as well as the angle between the LMA and LCx (Fig. 1). The workstation's AJ - 130 program was used to score any calcification seen in the vessels where angle measurements were taken. Coronary artery calcification (CAC) was assessed using non-contrast CT scans and quantified by the Agatston scoring method. Lesions with a density >130 Hounsfield Units (HU) and area ≥1 mm² were included. The total score was calculated by summing the values from the LMA, LAD, and LCx.

Statistical tests were conducted using SPSS V 18.0 (SPSS, Inc., Chicago, IL, USA). In this study, a dataset containing demographic variables (age, sex), coronary artery angle measurements (LMA-LAD, LMA-LCx, LAD-LCx), presence of calcification, and calcification scores was analyzed through a series of statistical methods. The distribution of continuous variables was examined. As the data approximated normal distribution, parametric tests were applied. The association between sex and presence of calcification was tested using the Chi-square test. The relationship between age and calcification was evaluated with a t-test. The coronary angles (LMA-LAD, LMA-LCx, LAD-LCx) were analyzed both in relation to the presence of calcification (binary) and calcification score (continuous). Comparisons of coronary angles between sexes were performed using independent-samples t-tests. The association between calcification scores and sex was examined with independent-samples t-tests. The relationship between age and coronary angles was assessed using Pearson's correlation analysis. Differences in coronary angles between patients with and without calcification were tested using independent-samples t-tests. ROC curves were generated for each angle to assess their predictive value for calcification.

In this study, a total of 164 participants were included, comprising 85 males and 79 females. The mean age of female patients was 54.5 ± 9.1 years, whereas the mean age of male patients was 50.7 ± 9.8 years. The coronary angles (LAD - LCx, LMA - LAD, and LMA - LCx) were compared between male and female patients. The minimum, maximum, and standard deviation (SD) values were calculated for each angle, and statistical significance was assessed using an independent samples t-test (Table 1).

Although not statistically significant (borderline), LAD-LCx angle suggested a slight tendency for males to have a wider angle ($p = 0.0515$). LMA - LAD angle shows no significant difference between males and females. Similarly, the LMA - LCx angle does not show any significant variation between the two sexes ($p>0.05$).

Upon examining the effect of sex on calcification, it was found that 55.29% (47 out of 85 men) of men developed calcification, whereas the corresponding percentage for women was 22.78% (18 out of 79 women). This situation was found to be statistically significant ($p \approx 0.00004$). Calcification scores of 18 female patients were determined as minimum 5 and maximum 1108. Mean values were found as 228.11±300.78. Calcification scores of 47 male patients were determined as minimum 1 and maximum 1624. Mean values

Table 1. Coronary bifurcation angles on computed tomography images

Angle Type	Male (Min)	Male (Max)	Male (Mean)	Male (SD)	Female (Min)	Female (Max)	Female (Mean)	Female (SD)	p-value
LAD-LCx	35.8°	132.7°	67.68°	15.75	32.8°	140.1°	62.37°	18.68	0.0515
LMA-LAD	119.3°	175.7°	147.04°	11.03	107.7°	166.6°	146.28°	12.83	0.6871
LMA-LCx	73.8°	168.1°	129.1°	17.05	87.7°	174.9°	131.28°	17.96	0.4279

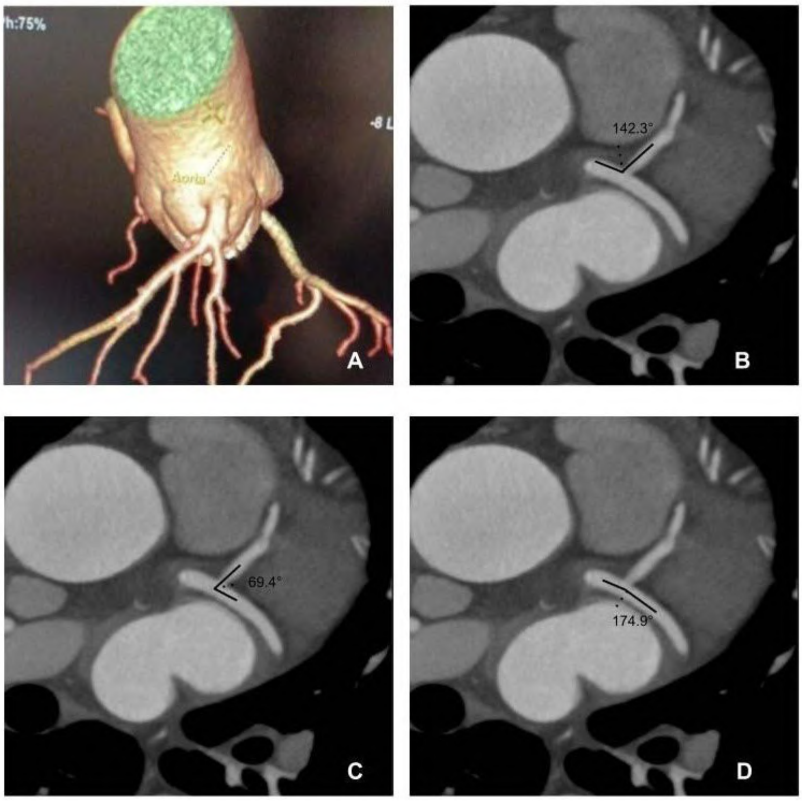


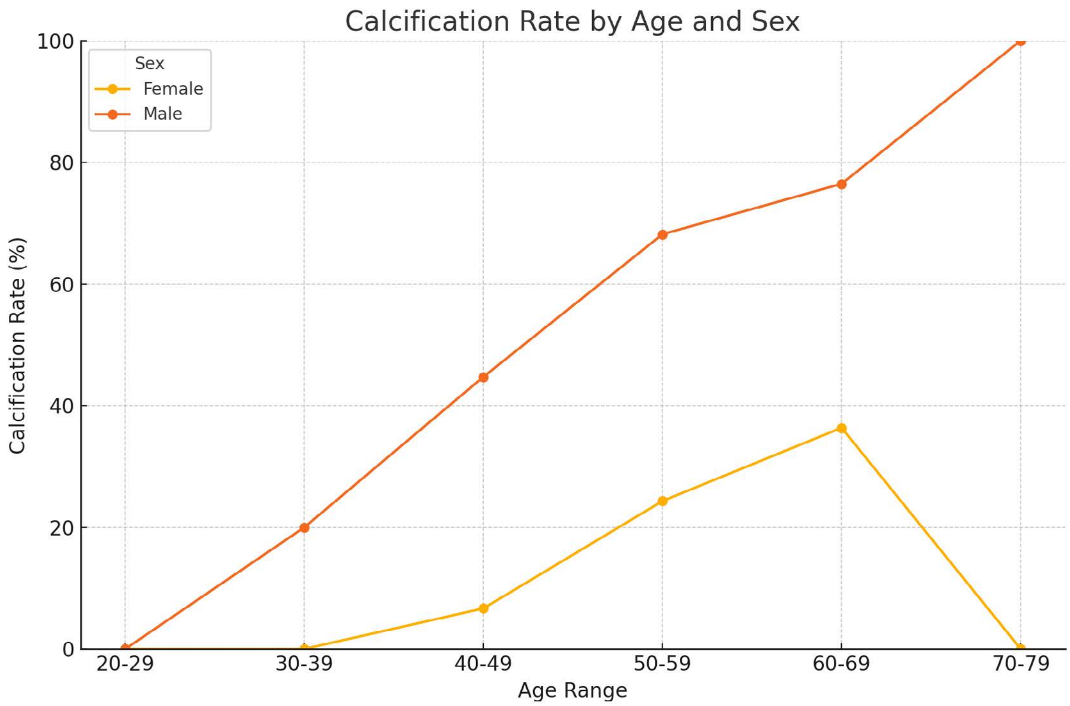
Fig. 1.- Coronary bifurcation angles on computed tomography images.

were found as 241.66±390.58. No statistical association was found between calcification scores and sex (p=0.8823).

In the analysis of vessels impacted by calcification in men, 24 patients had calcification only in the LAD, 4 patients in the LCx, and 1 patient in the LMA. 10 patients had both the LMA and LAD calcified, 4 patients had both the LMA and LCx calcified, 2 patients had the LAD and LCx calcified, and 2 patients had calcification in all three arteries. When the numbers are examined, LAD involvement is predominant in 38 of 47 male patients. In female patients, only LAD calcification was observed in 9 patients and only LCx calcification was observed in 1 patient. Calcification of the LAD and LCx was observed in 6 patients, calcification of the LAD and LMA in 1 patient, and calcification of all three arteries in 1 patient. LAD calcification was seen dominantly in 17 of 18 patients in women, as in men.

The mean age of patients with calcification was 55.05, while the mean age of patients without calcification was 50.86. The incidence of calcification increased significantly with increasing age (p = 0.0045). When stratified by sex, the mean age of female patients with calcification was 59.1 ± 5.8 years compared to 53.1 ± 9.5 years in those without calcification. Similarly, male patients with calcification had a mean age of 53.5 ± 8.7 years, whereas those without calcification had a mean age of 47.2 ± 10.0 years. When all participants were examined by age groups, increasing calcification was observed with age in both sexes. However, this increase begins at an earlier age in men, and those with calcification (calcification rate) among total participants in the same age group are generally higher than in women (Graph 1). (Note: In the 70–79 age group, only one female patient was included, and no calcification was detected; therefore, the calcification rate appears as zero in Graph 1).

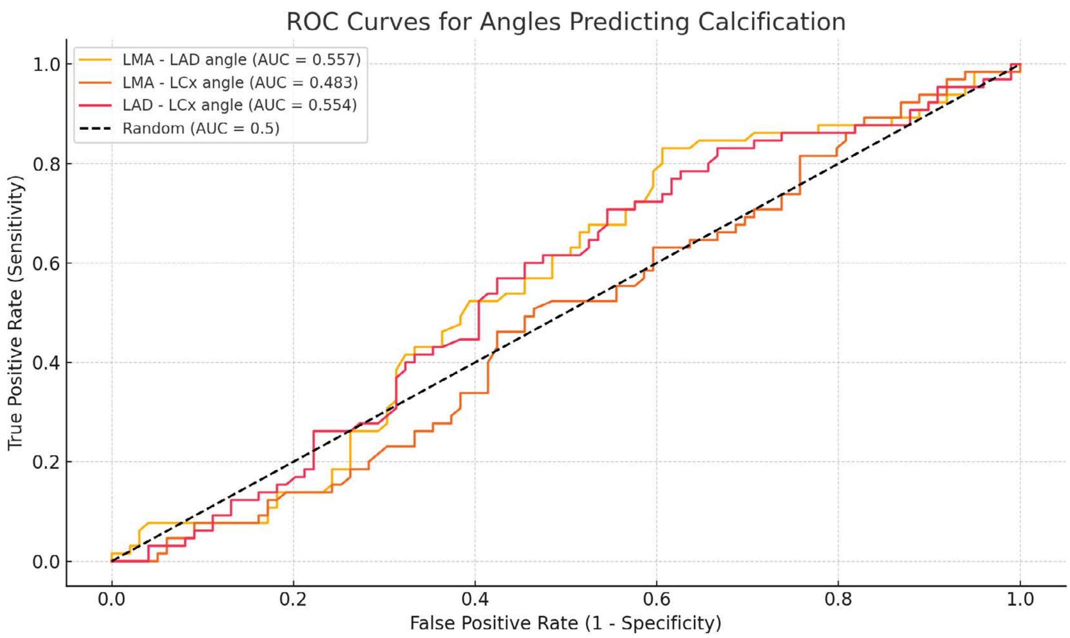
Considering that sex has no statistical effect on angles as mentioned before, the effect of angles on calcification was investigated. In order to obtain more accurate results, it was first investigated whether age had an effect on angles. Age factor was found to have a very weak positive correlation with the LMA - LAD angle (+0.075), a very weak negative correlation with the LMA - LCx angle



Graph 1. Calcification rate by age and sex. *Note: In the 70–79 age group, only one female patient was included, and no calcification was detected; therefore, the calcification rate appears as zero.

(–0.139), and finally almost no correlation with the LAD - LCx angle (–0.014). The mean LMA-LAD angle values for patients with calcification were 147.92 ± 11.02, while those without calcification were 145.86 ± 12.43. This was not statistically significant (p = 0.2671). The mean LMA - LCx angle values for patients with calcification were 129.41 ± 15.87, while those without calcification were 130.64 ± 18.52. This was also not statistically significant (p = 0.6493). Lastly LAD - LCx angle values for patients with calcification were 65.86 ± 14.54, while those without calcification were 64.64 ± 19.06. This was also not statistically significant (p = 0.6450).

Cut-off values for calcification were determined at each angle utilizing ROC analysis. The AUC value for the LMA - LAD angle was determined to be 0.557, indicating weak discriminating. With 83%



Graph 2. ROC curves for angles predicting calcification.

sensitivity and 39% specificity, the best cut-off was determined as 141.2°. The AUC value for the LMA - LCx angle was found to be 0.483. It was interpreted as having no discriminatory power. The AUC value for the LAD - LCx angle was determined to be 0.554, indicating weak discriminating. With 83% sensitivity and 33% specificity, the best cut-off was determined as 53.6°. Since AUC values were low, confirming that angles alone did not discriminate calcification well (Graph 2).

Comments

Age and sex are well-established non-modifiable risk factors for coronary artery calcification (CAC). Previous studies have shown that older individuals have a higher prevalence and severity of coronary artery disease (CAD), with more diffuse and calcified lesions (Gök et al., 1996; İkitimur et al., 2017). In line with this, our study found that the mean age of patients with calcification was significantly higher than those without (55.05 vs. 50.86 years, $p = 0.0045$).

Sex-related differences have also been consistently reported, with men developing CAC earlier and in greater severity than women (Kim et al., 2021; Yang et al., 2023). Consistently, the prevalence of calcification in our cohort was significantly higher in men (55.3%) than in women (22.8%) ($p < 0.001$), although mean calcium scores did not differ significantly between sexes ($p = 0.8823$).

Regarding the anatomical distribution of CAC, prior studies have shown the LAD as the most common site of early calcification (Alluri et al., 2015). Similarly, LAD was the most frequently affected vessel in our dataset, emphasizing its central role in early atherosclerotic plaque formation.

While bifurcation anatomy has been proposed as a contributor to local hemodynamics and plaque development (Gharleghi et al., 2025; Murasato et al., 2022), we observed no statistically significant association between bifurcation angles (LAD–LCx, LMA–LAD, LMA–LCx) and either the presence or severity of CAC. Only minimal, non-significant differences in LAD–LCx angles were seen between groups (65.9° vs. 64.6°, $p = 0.6450$; AUC = 0.554).

Taken together, our findings suggest that age and sex are stronger predictors of CAC than coronary bifurcation geometry. Nevertheless, variations in coronary anatomy, particularly at the LAD–LCx junction, may influence local hemodynamic conditions that favor early calcific deposition. Our study also provides updated anatomical and calcification data specific to the Western Anatolian population, addressing a gap in the regional literature.

This study has several limitations. The sample size was modest, the cross-sectional design prevents causal inference, and measurements were based on static imaging without computational fluid dynamics modeling. The single-center setting may also limit generalizability. Future studies with larger, multi-center cohorts and CFD analyses are warranted to clarify the role of coronary geometry in calcification development.

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