Received: 17 September 2023 | Revised: 29 September 2023 | Accepted: 1 October 2023

DOI: 10.1111/echo.15702

ORIGINAL ARTICLE

Echocardiography WILEY

Evaluation of left atrial and left ventricular functions with 3D speckle-tracking echocardiography in patients with coronary artery tortuosity

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Abstract

Background: Tortuosity in the coronary arteries is a very common entity encountered during angiography. The effect of coronary artery tortuosity (CAT) on the myocardium has not been completely investigated. The aim of the current study was to assess the effects of CAT on left atrial (LA) and left ventricular (LV) myocardial functions by 3D speckle-tracking echocardiography (3D-STE).

Methods: Seventy-five patients with CAT and 80 age- and gender-matched controls who proved to have normal coronary angiograms (CAG) were enrolled into the study. Following CAG, the 2D images were obtained first, and then 3D images were obtained for strain analysis.

Results: The LAS-r, LAS-active, and LV-GLS were significantly depressed in the CAT (+) group ($p < .001$, $p < .001$, $p = .012$, respectively). The multivariate regression models demonstrated that LAS-r ($p < .001$), LAS-active ($p = .009$), and LV-GLS ($p = .024$) were found to be independent factors predicting CAT.

Conclusion: The current study is the first to focus on the assessing both LA and LV myocardial dynamics in CAT (+) patients by strain echocardiography. The results of our study support the patients with CAT may have subclinical LA and LV myocardial involvements.

KEYWORDS
3D speckle-tracking echocardiography, coronary artery tortuosity, left atrial dysfunction, left ventricular dysfunction

1 | INTRODUCTION

Tortuosity in the coronary arteries is a very common entity encountered during angiography.[1,2] Coronary artery tortuosity (CAT) is defined as three fixed bends during both systole and diastole in at least one epicardial coronary artery, with each bend showing a 45° change in vessel direction in a projection that opens up the vessel profile.[3] The clinical significance and prognosis of CAT remains unclear; however, CAT is known to be associated with smoking, hypertension, and female gender.[4,5]

The contribution of CAT to myocardial ischemia and its effect on myocardial deformations are still under investigation.[6,7] Low blood pressure at the distal end of the tortuous arteries is accepted as the pathogenesis of myocardial ischemia.[8,9]

Conventional 2D echocardiography informs about the nature and function of the left and right myocardial chambers. However, 2D echocardiography is not sensitive enough to detect early cardiac abnormalities. Strain echocardiography, especially 3D speckle-tracking echocardiography, has been accepted to be an eligible, right, and dependable technique for the assessment of the left and right heart chambers and myocardial deformations on both these sides.[10–13]

Although there are very limited studies examining the impact of CAT on the LV with this sensitive method, we have not encountered any articles that previously assessed the effect of CAT on LA dynamics by strain imaging. Thus, we aimed to investigate LA myocardial deformation in this patient group by 3D-STE.

2 | MATERIALS AND METHODS

2.1 | Study population

The design of the current study is a cross-sectional observational study. A total of 155 consecutive patients were enrolled between May 2020 and September 2021. The patient [CAT (+)] group included 75 patients with CAT. The control [CAT (−)] group consisted of 80 age- and gender-matched patients who were selected in a consecutive manner from the catheterized patients during the same period and who proved to have normal coronary angiography (CAG). All patients enrolled into the study underwent CAG as a result of the presence of typical angina or positive noninvasive screening tests for myocardial ischemia. The rate of positive effort test among all patients was 58.5%. The remainder consisted of patients with myocardial perfusion scintigraphy with an ischemia rate of >10%.

The exclusion criteria were history of myocardial infarction (MI), percutaneous coronary intervention (PCI), and/or coronary artery by-pass graft (CABG), arrhythmia, heart failure (HFrEF, HFmrEF, or HFpEF), right and left bundle branch block, chronic hepatic and renal failure, uncontrolled hypertension, malignancy, congenital heart disease, and poor 3D echocardiographic image quality. The local ethics committee approved the present study. Our study was carried out in compliance with the ethical guidelines of the Declaration of Helsinki. An informed and signed consent form was obtained from all patients.

2.2 | Angiographic evaluation of the study population

CAG was performed to all the study patients via the femoral or radial route by the Judkins technique using 6 or 7-French right and left coronary catheters using Siemens AXIOM Artis (Erlangen, Germany). Two blinded expert interventional cardiologists analyzed the coronary angiograms without knowledge of the clinical status.

2.3 | Echocardiographic examination

All the echocardiographic evaluations were done by a single cardiologist, highly experienced in echocardiography and blinded to the group of the subject, on the morning following the CAG. Measurements and image obtaining were performed in accordance with the American Society of Echocardiography (ASE) criteria from the parasternal long-axis, parasternal short-axis and apical four chamber sections in the left lateral position, and subcostal section in the supine position with one-lead ECG monitoring.[14] Echocardiographic evaluations were performed with an easily accessible echocardiographic system (Vivid E9; GE Healthcare, Horten, Norway) with an appropriate M5S or 6S probe for patient size. Images from three consecutive cardiac cycles were acquired during a breath-hold at end-expiration. In the present study, 9 patients who had poor 3D image quality were excluded from the study. LVEF was obtained automatically with 4D auto LVQ. The stored echocardiographic data were exported to a separate workstation for off-line analysis. The endocardial border of the LV cavity was automatically detected by the software in 3D. If the auto endocardial border detection was judged as inaccurate by the examiner, the LA/LV endocardial borders were manually adjusted in multiplanar layout with a point-click method, immediately followed by secondary automated refinement of boundary detection according to the results. The analysis was performed off-line with the aid of a commercially available software package (EchoPAC 113 1.0; GE, Horton, Norway). LV GLS, GCS, GAS, and GRS were obtained for the strain analyses.

All 3D LA volumes were displayed in reconstructed apical four-chamber, apical two-chamber, and short-axis views and 3D cineloops were analyzed at 20—30 frames/s. To obtain correct 3D wall motion tracking the endocardial border was traced with the start point at the level of the mitral annulus in a counterclockwise direction. Pulmonary veins (PV) and left atrial appendage (LAA) were excluded from tracing. The 3D wall motion tracking was automatically performed using a 3 mm region of interest (ROI) and manual corrections were applied to all the trackings as required during the entire cardiac cycle. LA reservoir function was assessed using the left atrial strain-reservoir (LAS-r), and left atrial emptying fraction (LAEF) in 3D. LA contractile function was assessed using LAS-active: LA strain at the onset time of the P wave, and LAEF-active: (LA volume at the onset time of the P wave—LA minimum volume)/LA volume at the onset time of the P wave. LA conduit function was assessed by using LAS-passive: (LAS-r)—(LAS-active), and LAEF-passive: (LA maximum volume—LA volume at the onset time of the P wave)/LA maximum volume.[15]

2.4 | Reproducibility

The intraclass correlation coefficient for inter-observer comparisons of 3D LA volume, LAS, LAS-active, GLS, GCS, GAS, and GRS were .95 (95% CI, .89—.97), .81 (95% CI, .75–.85), .82 (95% CI, .79—.86), .92 (95% CI, .88—.94), .91 (95% CI, .87–.94), .86 (95% CI, .83–.93), and .89 (95% CI, .85—.93), while the intra-observer comparisons were .91 (95% CI, .87–.95), .82 (95% CI, .77—.88), .91 (95% CI, .86—.95), .83 (95% CI, .79—.86), .90 (95% CI, .87—.93), .91 (95% CI, .85—.97), and .87 (95% CI, .82—.92), respectively.

2.5 | Statistical analysis

SPSS 25.0 (IBM Corp., Armonk, NY, USA) program was used for variable analysis. Normally distributed continuous data were expressed as mean ± standard deviation. Continuous variables that are not

TABLE 1 Distribution of the tortuous coronary arteries.

Tortuous Coronary Artery	N: 75*n* (%)
LAD	15 (20)
CX	7 (9.3)
RCA	3 (4)
LAD + CX	8 (10.6)
LAD + RCA	6 (8)
RCA + CX	4 (5.3)
LAD + CX + RCA	32 (42.6)

Abbreviations: CX, circumflex artery; LAD, left anterior descending coronary artery; RCA, right coronary artery.

normally distributed were expressed as median, and categorical variables were expressed as n and percentages. Data were tested for normal distribution using the Kolmogorov–Smirnov test. To compare categorical variables, Pearson chi-square and Fisher Exact tests were tested. To compare parametric continuous variables, Student t test was used and to compare nonparametric continuous variables, the Mann-Whitney U test was used. Multivariate logistic regression analysis was used to identify independent predictors of CAT. Variables were examined at 95% confidence level. A *p*-value < .05 was considered as statistically significant.

3 | RESULTS

It was found that the left anterior descending coronary artery (LAD) was the most affected artery by the tortuosity both alone and in combination with other coronary arteries (81.2%) in the current study (Table 1).

The clinical and laboratory characteristics of both groups were presented in Table 2. The mean age of the patients was 57.1 ± 10.6 years. Patients with CAT were more hypertensive than those without ($p = .019$).

There were no significant differences between the two groups regarding the 2D echocardiographic results except E/A value ($p = .036$) (Table 3).

3.1 | 3D-STE results of the study population

Left atrial and ventricular strain values are presented in Table 4. The LAS-r, LAS-active, and LV-GLS were significantly depressed in the CAT (+) group than in the control group ($p < .001$, $p < .001$, $p = .012$, respectively) (Table 4, Figure 1).

No significant difference was observed in terms of LV-GCS, LV-GAS, LV-GRS, LAS-passive, LAEF, LAEF-active, and LAEF-passive ($p = .081$, $p = .415$, $p = .798$, $p = .518$, $p = .365$, $p = .509$, and $p = .924$, respectively) (Table 4).

The univariate and multivariate analysis results showed that LAS-r ($p < .001$, Odds ratio (OR) = 3.88, 95% Confidence interval (C.I.) = 1.95–8.41), LAS-active ($p = .009$, OR = 2.69, 95% CI = 1.75–5.23), and LV-GLS ($p = .024$, OR = 2.27, 95% CI = 1.53–4.45) were found to be independent factors predicting CAT (Table 5).

TABLE 2 Clinical and laboratory data of the study population.

	Control group (n = 80)	CAT (+) group (n = 75)	*P*-value
Age	56.8 ± 10.7	57.4 ± 10.5	.612
Male gender, *n* (%)	42 (52.5)	41 (54.6)	.227
BMI (kg/m^2)	25.5 ± 2.7	26.2 ± 2.8	.345
Heart rate (bpm)	77 ± 14	80 ± 12	.561
Hypertension, *n* (%)	47 (62.6)	54 (72)	.019
Hyperlipidemia, *n* (%)	24 (32)	25 (33.3)	.806
Diabetes mellitus, *n* (%)	18 (22.5)	20 (26.6)	.133
Smoking, *n* (%)	19 (23.7)	22 (29.3)	.057
Fasting glucose (mg/dL)	115.2 ± 32.4	117.6 ± 36.3	.313
Creatinine (mg/dL)	.91 ± .4	.93 ± .4	.278
Hemoglobin (g/dL)	14.6 ± 1.3	14.5 ± 1.4	.852
Platelet (K/μL)	281000 ± 105000	288000 ± 110000	.407
TC (mg/dL)	173.5 ± 41.4	174.2 ± 41.5	.529
LDL-C (mg/dL)	105.4 ± 30.5	112.3 ± 32.2	.261
HDL-C (mg/dL)	44.5 ± 9.5	43.8 ± 9.6	.747
TG (mg/dL)	153.8 ± 36.5	155.6 ± 38.4	.218

Abbreviations: BMI, body mass index; CAT, coronary artery tortuosity; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride.

4 | DISCUSSION

In the present study, it was aimed to assess the LA and LV myocardial dynamics in patients with and without CAT by 3D-STE. According to present study, it has been shown that both left atrial and left ventricular dynamics are affected in CAT (+) patients. To the best of our knowledge, our article is the first to evaluate the myocardium with 3D-STE in terms of both atrial and ventricular subclinical dysfunction in patients diagnosed with CAT.

The etiology of CAT is still unclear. There are several possible mechanisms implicated in the development of CAT. The most widely accepted mechanism is the degeneration of the elastin layer in the vessel wall. The clinical significance of CAT should be evaluated from various perspectives. Coronary flow disturbance in a tortuos coronary artery may result in myocardial ischemia due to decreased perfusion

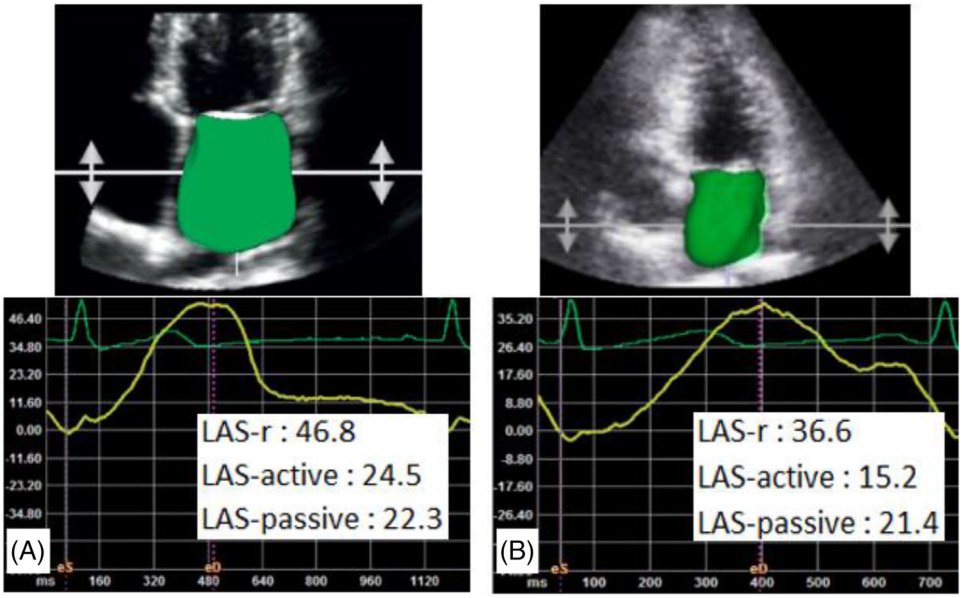

FIGURE 1 (A) LAS values of a healthy person from the control group. (B) LAS values of a patient from the CAT (+) group. Abbreviations: CAT, coronary artery tortuosity; LAS, left atrial strain.

TABLE 3 Two-dimensional echocardiographic data.

	Control group (n = 80)	CAT (+) group (n = 75)	*P*-value
LVSWT (mm)	9.8 ± 1.4	10.4 ± 1.7	.216
PWT (mm)	9.1 ± 1.5	9.7 ± 1.8	.453
LVEDD (mm)	47.9 ± 4.3	46.6 ± 4.1	.305
LVESD (mm)	34.3 ± 3.2	33.5 ± 3.1	.626
Left atrium diameter (mm)	36.4 ± 4.3	38.7 ± 4.4	.083
LAVI (mL/m^2)	26.5 ± 6.8	28.2 ± 7.3	.062
LV mass index (g/m^2)	78.6 ± 18.5	82.5 ± 19.4	.095
E/A	1.47 ± .4	1.18 ± .3	.036
Lateral e′ (cm/s)	10.7 ± 3.5	11.2 ± 3.6	.478
Septal e′ (cm/s)	8.9 ± 1.3	8.9 ± 1.6	.917
dT (ms)	221.7 ± 36.5	248.5 ± 39.6	.058
TAPSE (mm)	22.5 ± 3.8	22.1 ± 3.5	.845

Abbreviations: CAT, coronary artery tortuosity; dT, deceleration time; LAVI, left atrial volume index; LVEDD, left ventricular end-diastolic diameter; LVESD, left ventricular end-systolic diameter; LVSWT, left ventricular septal wall thickness; PWT, posterior wall thickness; TAPSE, tricuspid annular plane systolic excursion.

TABLE 4 Three-dimensional echocardiographic data.

	Control group (n = 80)	CAT (+) group (n = 75)	*P*-value
LVEF (%)	64.7 ± 4.8	63.4 ± 4.9	.543
LVEDV (mL)	97.4 ± 21.5	96.5 ± 22.3	.722
LVESV (mL)	38.2 ± 8.6	38.5 ± 8.1	.695
LV GLS (%)	−22.8 ± 3.1	−16.9 ± 3.4	.012
LV GCS (%)	−25.6 ± 4.4	−23.2 ± 3.9	.081
LV GAS (%)	−37.7 ± 4.2	−35.8 ± 4.5	.415
LV GRS (%)	43.6 ± 5.5	43.4 ± 5.8	.798
LAS-r (%)	46.1 ± 4.4	32.5 ± 4.6	<.001
LAS-active (%)	24.4 ± 4.8	12.6 ± 4.9	<.001
LAS-passive (%)	21.3 ± 3.7	20.7 ± 3.9	.518
LAEF (%)	56.6 ± 7.1	55.9 ± 7.4	.365
LAEF-active (%)	38.4 ± 9.2	37.7 ± 9.5	.509
LAEF-passive (%)	46.2 ± 10.7	46.5 ± 9.8	.924

Abbreviations: CAT, coronary artery tortuosity; GAS, global area strain; GCS, global circumferential strain; GLS, global longitudinal strain; GRS, global radial strain; LAEF, left atrial emptying fraction; LAS-r, left atrial strain-reservoir; LV, left ventricular; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; LVESV, left ventricular end-systolic volume.

pressure distal to the convoluted segment. Increased shear stress in the tortuous vessel can promote atherosclerotic plaque formation and acute coronary syndrome.[16,17]

2D echocardiography provides information about the structure and function of the left atrium (LA) and left ventricle (LV). However, 2D echocardiography is not sensitive enough to detect early cardiac abnormalities. 3D speckle-tracking echocardiography (3D-STE) has been accepted to be an eligible, right, and dependable technique for the assessment of LA and LV myocardial dynamics in the different cardiovascular diseases.[18,19] In this study, we evaluated the left atrial and ventricular deformations of patients diagnosed with CAT based on CAG results with 3D-STE.

Differences in tortuous coronary arteries have been observed between systole and diastole, and between circumferentially and longitudinally oriented coronary arteries. Therefore, deterioration in left ventricular myocardial deformation is inevitable in this setting of relative ischemia due to the decrease in coronary distal flow. In our

TABLE 5 The univariate and multivariate analysis for CAT.

	Univariate		Multivariate	
	Odss ratio (%95 C.I.)	*P*-value	Odss ratio (%95 C.I.)	*P*-value
LAVI	1.36 (1.05–1.75)	.072		
Hypertension	1.44 (.93–2.68)	.053		
Smoking	.95 (.68–1.22)	.114		
LAS-r	2.92 (1.65–5.94)	<.001	3.88 (1.95–8.41)	<.001
LAS-active	2.43 (1.36–3.85)	.017	2.69 (1.75–5.23)	.009
LV-GLS	2.18 (1.25–3.08)	.036	2.27 (1.53–4.45)	.024
LV-GCS	1.32 (.84–2.25)	.124		
E/A	.89 (.65–1.16)	.209		

Abbreviations: CI, confidence interval; CAT, coronary artery tortuosity; GCS, global circumferential strain; GLS, global longitudinal strain; LAS, left atrial strain; LAVI, left atrial volume index; LV, left ventricular.

study, we demonstrated that LV-GLS was significantly decreased in the CAT (+) patients than in the other group (p = .012). LV myocardial involvement causes diastolic dysfunction and ultimately results in LA involvement.

Since the left atrium is directly related to the filling of the left ventricle, dysfunctions in the left ventricle cause effects on the left atrium, and similarly, dysfunctions in the left atrium cause effects on the left ventricle. Early detection of subclinical dysfunctions in the left atrium plays an important role in the effective management of many cardiac diseases.[20,21] Several advanced imaging methodologies have been demonstrated to be useful for non-invasive assessment of LA. Recently, as in the evaluation of the left ventricle, analysis of left atrial deformations with 3D strain imaging is one of the recommended methods.[22–24] In our current study, we demonstrated that the LAS-r and LAS-active were significantly depressed in the CAT (+) group than in the control group ($p < .001$, $p < .001$, respectively). We have not encountered any studies that previously evaluated the effect of CAT on LA myocardial dynamics with 3D-STE.

In a cross-sectional study, Khosravani-Rudpishi et al. showed that the 2D speckle-tracking echocardiography-derived indices of longitudinal deformation of the LV myocardium were not significantly different between the patients with severe CAT and controls.[25] This study is important about assessing the patients with CAT by strain echocardiography even if the results were not significant. Their study has the expected limitations of 2D-STE, such as longer examination times, miss-tracking, and angle dependence. 3D-STE, having the potentials to overcome these limitations, provides a more beneficial, accurate, and convenient assessment in this clinical setting. In a pioneering study investigating LV function with 3D-STE in patients with CAT, the authors demonstrated that LV-GLS was depressed in patients with CAT compared to the control group.[26] In our current study, although LV-GLS was found to be depressed in CAT (+) patients, supporting this study, left atrial functions were also examined, and LAS-r and LAS-active values were found to be decreased.

Although CAT is frequently encountered in angiography and is considered to be a benign entity, it cannot be said to be an innocent finding according to the results of our study and other studies in the literature. The importance of CAT remains elusive and is needed further investigation.

5 | LIMITATIONS

Limitations of our study: (1) Low number of patients. (2) The effects of left atrial and ventricular strain values on the prognosis in patients with CAT are unknown. Prospective studies are needed. (3) Advanced methods such as cardiac MRI were not used. 4) We did not perform artery-specific strain analysis.

6 | CONCLUSION

The present study is the first to focus on the assessing both LA and LV myocardial functions in patients with CAT by 3D-STE. We found that CAT had a negative effect on LA and LV mechanics. Our results support that patients with CAT may have subclinical LA and LV myocardial abnormalities even though they are apparently healthy. So, these individuals should be followed more closely.

ACKNOWLEDGMENTS

This work did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sector.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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How to cite this article: Taskin U, Mammadov G, Topaloglu C, Koyuncu I, Dogdus M. Evaluation of left atrial and left ventricular functions with 3D speckle-tracking echocardiography in patients with coronary artery tortuosity. *Echocardiography*. 2023;40:1237–1242. https://doi.org/10.1111/echo.15702