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Computed tomography in the left lateral decubitus position before catheter ablation in patients with atrial fibrillation

Aim	The study aimed to determine the efficacy of cardiac computed tomography angiography (CCTA) for diagnosing left atrial appendage (LAA) thrombus before catheter ablation with the patient in the left lateral decubitus position and, also, to evaluate the risk factors for thrombus formation.
Material and methods	This retrospective, cohort study included 101 patients with atrial fibrillation. All patients underwent transthoracic echocardiography (TTE) and left lateral decubitus CCTA. Transesophageal echocardiography (TEE) was performed to confirm or exclude LAA thrombus. Patients with allergic reactions to iodinated contrast media, increased serum creatinine, hyperthyroidism, pregnancy, and age<18 years were excluded. The CHA_2-DS_2-VASc and HAS-BLED scores were calculated for each patient.
Results	All LAA thrombi detected on CCTA were confirmed by TEE. Higher CHA_2-DS_2-VASc, HAS-BLED scores, enlarged LA, and the anteroposterior dimension of the left atrium were significantly associated with the presence of LAA thrombus. A LAA cauliflower shape was a predictor of thrombus. An increase of LAA volume by 1 ml increased the chances of LAA thrombus and cerebral ischemic infarct by 2%. The growth of the LAA anteroposterior diameter by 1 cm increased the risk of LAA thrombus by 190% and of cerebral infarct by 78%. An increase in the CHA_2DS_2-VASc score by 1 point increased the risk of thromboembolism and cerebral infarction by 12%.
Conclusions	CCTA performed in the left lateral decubitus position of the patient is an optimal screening tool to detect or exclude LAA thrombus before catheter ablation because of atrial fibrillation. CCTA has predictive value for risk of thrombosis formation in LAA.

Keywords	Computed tomography; left atrial appendage thrombosis; echocardiography; atrial fibrillation
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Introduction

Cardioembolism is one of the major causes of ischemic stroke and accounts for 15% – 30% of all cerebral infarctions [1, 2]. Atrial fibrillation (AF) causes severe morbidity and death, burdening individuals, society, and the health economy [3]. The process by which patients with AF experience a stroke is well studied.

Once the patient develops AF, the dysrhythmia leads to myocardial contractile dysfunction and blood stasis, which further leads to left atrial (LA) thrombus formation and increases the risk of arterial thromboembolism [4]. Approximately 90% of all thrombi in patients with AF are localized in the LA appendage (LAA) [5–8].

Current strategies for AF treatment include both pharmacological and interventional approaches [9]. Electrical cardioversion with catheter radiofrequency pulmonary vein antral isolation is one of the effective approaches to the treatment of persistent AF [10, 11]. However, the presence of blood clots in the LAA is regarded as a contraindication for electric cardioversion [12, 13]. Normalization of sinus rhythm, restoration of contractility and blood flow can lead to detachment of a blood clot in the LAA and subsequent cardioembolic stroke. Thus, detecting the presence of a LAA thrombus and assessing the risk of stroke in patients with AF is critical.

The acknowledged gold standard for the detection of LAA thrombus is transesophageal cardiography (TEE)

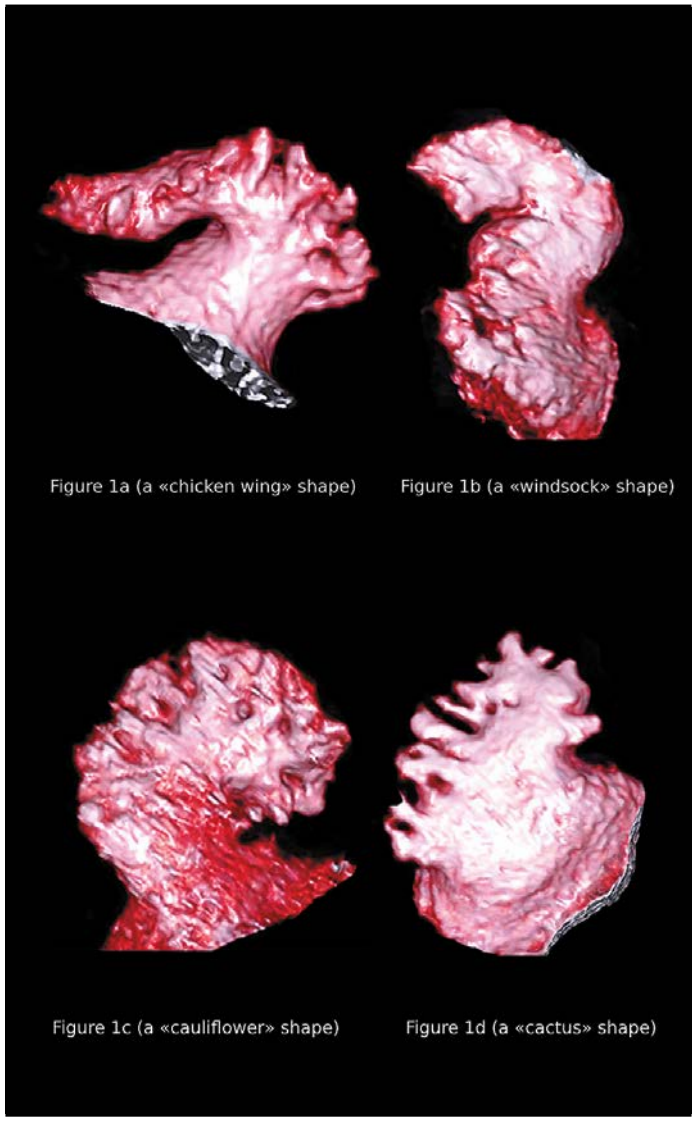
[14, 15]. TEE is a semi-invasive procedure with various types of potential complications [16], but, generally, the TEE is a safe diagnostic technique across a wide range of patients. However, life-threatening consequences have been observed. Major TEE-related problems are reported at rates from 0.2% to 0.5% [17]. Lennon et al. reported a 1.2% increase in the incidence of gastrointestinal injuries after TEE [18]. Mechanical damage of the esophagus and stomach can result in life-threatening hemorrhage. TEE is an "operator-dependent method", but the method is generally safe if performed by well-skilled personnel. Esophageal disease with a known stricture, diverticula, varices, or tumor; a history of esophagus or stomach surgery; a perforated viscus; or a patient who is not cooperative are all contraindications for TEE. Cervical spine disease, hiatal hernia, coagulopathy, past chest radiation, and face or airway injuries are some of the relative contraindications for TEE.

Cardiac computed tomography angiography (CCTA) is widely used in cardiological practice. Recent studies have illustrated that the use of an additional, delayed acquisition with the patient in the supine and prone positions improves the accuracy of CCTA in the diagnosis of LAA thrombosis [19]. However, delayed scanning increases the radiation dose, which is undesirable. Scanning in the prone position is also attractive due to its high diagnostic accuracy [20]. To date, no studies have investigated the option of performing LAA CCTA in the left lateral decubitus position. We supposed that this new approach would result in better depiction of the LA and LAA cavities. In this study, we analyzed the efficacy of left lateral decubitus CCTA for diagnosing LAA thrombus as a screening tool before catheter ablation, and we evaluated the risk factors for thrombus formation and thromboembolism complications in patients with AF.

Material and methods

101 patients diagnosed with AF who were admitted to our institution between May 2021 and January 2022 were retrospectively recruited in the study. TEE was performed to confirm or exclude a LAA thrombus. All patients underwent transthoracic echocardiography (TTE) followed by left lateral decubitus CCTA. The exclusion criteria for CCTA were: allergic reactions to iodine contrast media, increased serum creatinine, thyroid disease (hyperthyroidism), pregnancy, and age<18 years. The CHA_2-DS_2-VASc and HAS-BLED scores were calculated for each patient. The institutional ethics committee (JSC: National Scientific Cardiac Surgery Center, Local Bioethics Committee) approved this study, and it was conducted according to the Declaration of Helsinki. All the patients provided written informed consent.

Figure 1. LAA morphology



1a) Chicken wing shape; **2a**) Windsock shape; **3a**) Cauliflower shape; **4a**) Cactus shape.

Figure 2. LA volume as measured on CCTA

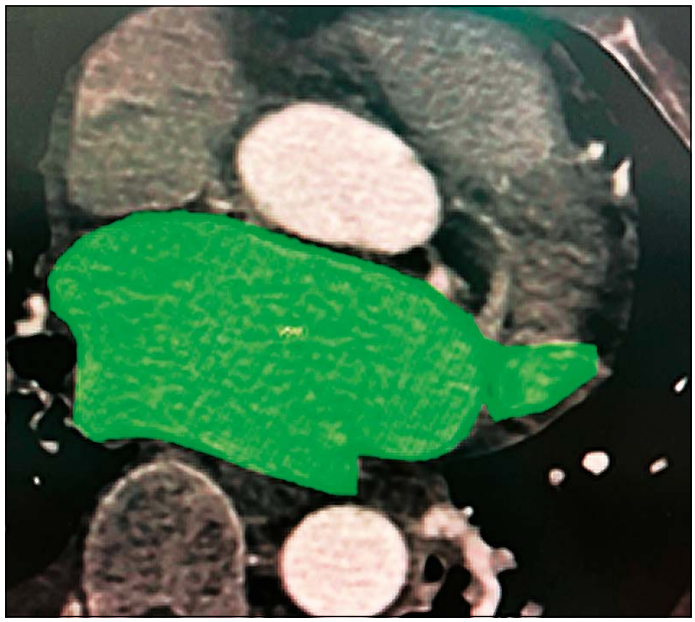


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Figure 3. LAA thrombus (at arrow) detected by CCTA

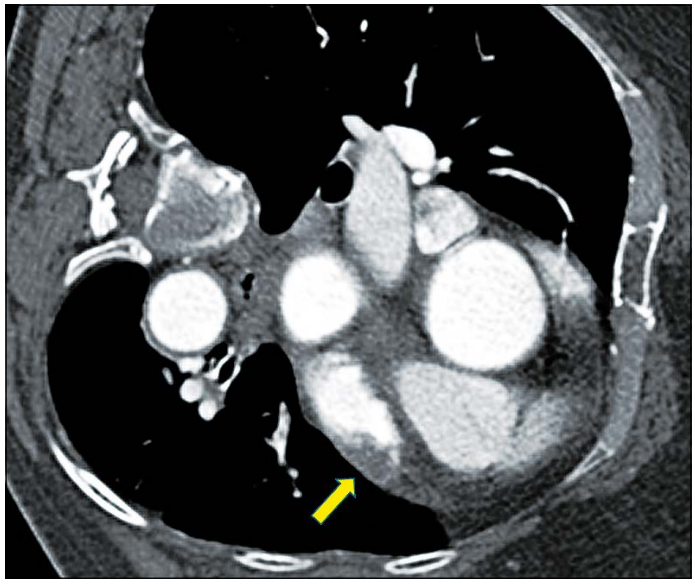
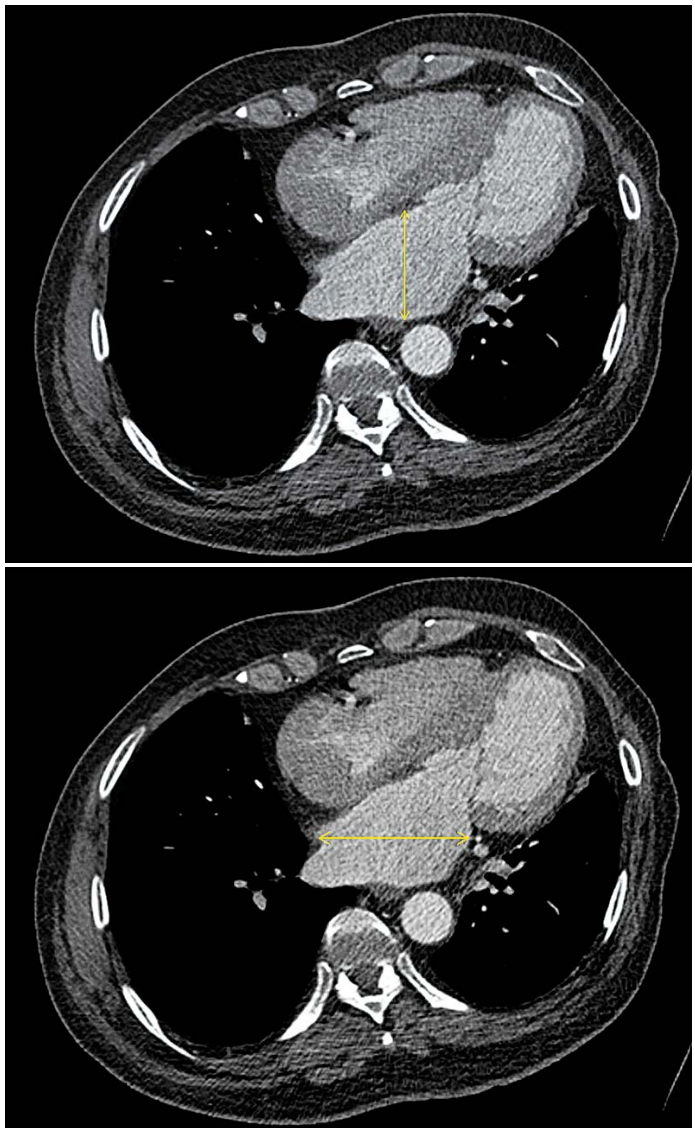


Figure 4. LA images



a) Anteroposterior size of the left atrium.
b) Transverse dimension of the left atrium.

Transesophageal and transthoracic and echocardiography

For assessment of the LA and LAA, TEE was performed with Phillips iE33 (Philips Medical Systems, USA) system. For the assessment of left ventricular (LV) function, i.e., LV volumes and ejection fraction (EF), valve function, myocardial thickness, and contractility, TTE was performed with Phillips EPIQ7 (Philips Medical Systems, USA).

Cardiac computed tomography

CCTA was performed with Siemens Somatom Definition 64-row scanner (Siemens Healthineers, Germany) using retrospective ECG- gating. The slice thickness was 0.625 mm, slice overlap was 0.2 mm. The patients were placed in the left lateral decubitus position. CCTA was performed with intravenous bolus injection of non-ionic contrast media (iohexol, concentration 350 mg iodine/ml) with an Ohio Tandem automatic CT injector (Ulrich, Germany). This volume was calculated based on the patient's weight, 1 ml of contrast media per 1 kg of body weight. The contrast media was injected into the cubital IV cannula at rate of 5 ml/s followed by a 70 ml bolus of saline solution. The CCTA scan was performed with aid of contrast media bolus tracking. The region of interest was placed inside the lumen of the aortic arch. The threshold for scanning start was set to 140 Hounsfield units. The delay between the trigger detection and contrast media injection was set to 10 s. No beta-blockers were used during CCTA scans to decrease the heart rate.

Two experienced cardiologists analyzed the TEE results, and two experienced radiologists performed the CCTA analysis. Uniform filling of the LAA was regarded as indication of absence of a LA thrombus. A clear defect in LAA filling was regarded as a thrombus. The LA anteroposterior and transverse dimensions were measured, and the LAA morphological structure was assessed. The LAA morphology was classified according to four categories: 1, chicken wing; 2, windsock; 3, cauliflower; 4 cactus (Figure 1 a, b, c, d). The LA volume was measured on the Syngo Via workstation using the volume application along the LA inner contour. Figure 2 shows an image for LA volume calculation. Figure 3 illustrates the LAA thrombus detected by CT. Figures 4 a and 4 b demonstrate the LA dimensions as measured by CCTA.

CHA_2-DS_2-VASc and HAS-BLED scores

Stroke and bleeding risks were assessed using the CHA_2DS_2-VASc and HAS-BLED scores. One point was given for each of the following conditions: history of hypertension, diabetes, congestive heart failure, cardiovascular disease, stroke or transient ischemic attack, or female gender. Hypertension (uncontrolled systolic blood pressure >160 mmHg), abnormal renal and/or liver function,

Table 1. Demographic and medical characteristics of the patients

Variable	(n=101)	Anteroposterior LA size, cm	4.49±0.87
Age, yrs	60±11	Transverse LA dimension, cm	7.2±0.95
BMI, kg/m^2	30±6	*Anticoagulants*	
CHA_2DS_2-VASc score	2±1	Rivaroxaban	72 (71%)
HAS-BLED score	0.9±0.8	Dabigatran	12 (12%)
Coagulogram values		Enoxaparin sodium	7 (7%)
PT, s	13.8±5.5	Apixaban	7 (7%)
INR, s	1.2±0.52	Warfarin	3 (3%)
Fibrinogen, g/l	3.2±0.7	*Arterial hypertension*	
APTT, s	39±9	Yes	77 (76%)
Echocardiography values		*Coronary atherosclerosis*	
LVESD, cm	3.5±0.6	Yes	59 (58%)
LVEDD, cm	4.5±0.7	*Diabetes*	
LVESV, ml	44.2±21	Yes	11 (11%)
LVEDV, ml	100.4±37	*Heart failure*	
LVSV, ml	54.5±15	LVEF≤39%	3 (3%)
LVEF, %	56.4±8.2	40≤ LVEF ≤49%	11 (11%)
LVESVI, ml/m	23.2±11	LVEF≥50%	87 (86%)
LVEDVI, ml/m	52.4±18.8	*Assessment of heart valves*	
CCTA		Normal	76 (75%)
LA volume, ml	120.2±33.9	Mitral valve regurgitation	25 (25%)
LAA shape		*Fibrillation form*	
Cauliflower	29 (29%)	Paroxysmal	37 (37%)
Chicken wing	18 (17%)	Persistent	50 (49%)
Windsock	29 (29%)	Long-term persistent	12 (12%)
Cactus	25 (25%)	Constant	2 (2%)

Data are mean ± SD or n (%). APTT, activated partial thromboplastin time; BMI, body mass index; CCTA, cardiac computed tomography angiography; LVEDD, left ventricular end-diastolic dimension; LVEDV, left ventricular end-diastolic volume; LVESD, left ventricular end-systolic dimension; LVESV, left ventricular end-systolic volume; LVESVI, left ventricular end-systolic volume index; LVEDVI, left ventricular end-diastolic volume index; LVSV, left ventricular stroke volume; LVEF, left ventricular ejection fraction; LA, left atrium; PT, prothrombin time; TTE, transthoracic echocardiography.

previous stroke, bleeding history or predisposition, labile international normalized ratios, elderly, and concomitant drugs and/or alcohol excess are all included in the acronym HAS-BLED, and each was assigned a point.

Statistical analysis

Data were analyzed with statistical software STATA 16.0. The presence or absence of LAA thrombus was considered as an outcome. For the bivariate analysis, simple logistic regression was used. The unadjusted odds ratios are presented to show the influence of sociodemographic and medical characteristics on the outcome. If the assumptions for performing logistic regression were not met, a non-parametric Fisher's exact test was used. The normality of distribution was checked with the Shapiro-Wilk test. The significance level was set at 0.05 for all tests.

Results

A total of 101 patients were enrolled. CCTA was performed during the AF rhythm. CCTA detected nine cases of LAA thrombi before ablation. TEE verified the presence of thrombus in the LAA in these nine patients. 92 patients (91%) who underwent LA vein isolation had no LAA filling defects on CCTA images, as verified by TEE.

The patients' mean age was 60 yrs, ranging from 25 to 81 yrs. Men represented 54.5% of the patients, and the mean body mass index was 30 kg/m^2. The mean CHA_2DS_2-VASc score was 2, ranging from 0 to 5, and the mean HAS-BLED score was 0.9, ranging from 0 to 5. The average LA volume measured by cardiac CT was 120.2 ml. The patients' clinical and demographic characteristics are shown in Table 1.

With echocardiography results are taken as the gold standard, the sensitivity and specificity of the left lateral CCTA were 100%. The positive and negative predictive values of CCTA detection of the true thrombus were 100%. The diagnostic efficacy of left lateral CCTA is given in Table 2.

Higher CHA_2-DS_2-VASc and HAS-BLED scores and an enlarged LA and LA anteroposterior dimension were significantly associated with LAA thrombus ($p<0.05$). An LAA cauliflower shape was also a predictor of LAA thrombus ($p<0.001$). Multivariate logistic regression showed that an increase in the CHA_2DS_2-VASc score by 1 point increased the risk of LAA thrombus by 500% ($p<0.001$) (Table 3); an

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increase in the HAS-BLED score by 1 point increased the risk of blood clot formation by 200% (p=0.044); and an increase in LAA volume by 1 ml increased the risk of LAA thrombus by 2% (p=0.019). An increase in the LAA anteroposterior size by 1 cm increased the risk of LAA thrombus by 290% (p=0.020) (Table 3). The presence of LAA thrombus was significantly associated with diabetes mellitus (p=0.003) (Table 4).

An increase in the CHA_2DS_2-VASc score by 1 point raised the risk of thromboembolism and cerebral infarct by 12%. An increase in LAA volume by 1 ml and in the LA anteroposterior dimension increased the risk of acute cerebral infarct by 2% and 78%, respectively (Table 5).

Table 2. Diagnostic efficacy of the left lateral decubitus CCTA

	Negative CCTA	Positive CCTA
Negative TEE†	92	92
Positive TEE†	9	9†

Echocardiography results were taken as the gold standard.
Positive predictive value = TP/(TP+FP) = 9/(9+0) = 100%.
Negative predictive value = TN/(TN+FN) = 92/(92+0) = 100%.
Accuracy = (TP+TN)/(TP+TN+FP+FN) = (9+92)/(9+92+0+0) = 100%.

Table 3. Association between sociodemographic and medical characteristics of patients without and with LAA thrombus

Variable	No LAA thrombus (n=92, 91%)	LAA thrombus (n=9, 9%)	OR (95% CI)[a]	p-value
Age, yrs	60±11	65±8	1.06 (0.98; 1.15)	0.148
BMI, kg/m²	30.2±5.9	30.04±4.2	0.99 (0.88; 1.12)	0.927
CHA_2DS_2-VASc score	1.36±1.12	3.67±0.87	5.05 (2.09; 12.2)	<0.001
HAS-BLED score	0.8±0.9	1.4±0.7	2.06 (1.02; 4.18)	0.044
CCTA				
LA volume, ml	117.6±33.3	147.3±28.6	1.02 (1.01; 1.04)	0.019
LA shape				
Cactus	25 (27%)	0	–	0.068b
Cauliflower[b]	21 (23%)	8 (89%)	–	<0.001[b]
Chicken wing	18 (20%)	0	–	0.157[b]
Windsock	28 (30%)	1 (11%)	–	0.207[b]
LA antero-posterior size, cm	4.43±0.82	5.52±1.09	2.94 (1.18; 7.28)	0.020
LA transverse dimension, cm	7.3±0.97	7.5±0.72	1.25 (0.59; 2.63)	0.565

Data are mean ± SD or number (%).
[a] Unadjusted rates. [b] Fisher's exact test. BMI, body mass index; CCTA, cardiac computed tomography angiography; LA, left atrium; LAA, left atrium appendage; OR, odds ratio.

The association between comorbid conditions and an acute cerebrovascular accident was checked separately. Although the logistic regression showed that the presence of arterial hypertension increased the odds of CVA to 194%, the p-value was insignificant (p=0.548). The patients with mitral valve regurgitation had 245% higher odds of CVA compared to normal ones; however, the p-value was 0.263.

Discussion

There are no previous reports showing the diagnostic accuracy of left lateral decubitus CCTA for detection of LAA thrombus. In this study, we found that performance

Table 4. Association between LAA thrombus and comorbid conditions

Variable	No LAA thrombus (n=92, 91%)	LAA thrombus (n=9, 9%)	OR (95% CI)[a]	p-value
Arterial hypertension				
No	22 (24%)	2 (22%)	ref	–
Yes	70 (76%)	7 (78%)	1.1 (0.21; 5.69)	0.909
Coronary atherosclerosis				
No	38 (41%)	4 (44%)	ref	–
Yes	54 (59%)	5 (56%)	0.88 (0.22; 3.49)	0.856
Diabetes				
No	85 (92%)	5 (56%)	ref	–
Yes	7 (8%)	4 (44%)	9.71 (2.12; 44.6)	0.003
Heart failure				
LVEF≤39%	2 (2%)	1 (11%)	–	–
40≤ LVEF ≤49%	11 (12%)	0	–	–
LVEF≥50%	79 (86%)	8 (89%)	–	–
Assessment of heart valves				
Normal	71 (77%)	5 (56%)	ref	
Mitral valve regurgitation	21 (23%)	4 (44%)	2.7 (0.67; 10.9)	0.164
Fibrillation form				
Paroxysmal	35 (38%)	2 (22%)	–	–
Persistent	46 (50%)	4 (45%)	–	–
Long-term persistent	10 (11%)	2 (22%)	–	–
Constant	1 (1%)	1 (11%)	–	–

Data are number (%). [a] Unadjusted rates. LAA, left atrium appendage; LVEF, left ventricular ejection fraction; OR, odds ratio; ref, reference value.

of CCTA in the patients placed in the left lateral decubitus position provided satisfactory LA and LAA opacification without false-positive results. This scanning position is more physiological because the LAA is in a vertical position and contrast filling improves. All patients who did not have thrombi in the LAA according to CCTA results underwent successful, complication-free ablation, which further supports the use of this scanning method.

Spagnolo et al. demonstrated that CCTA in a supine position with additionally delayed scanning at 6 min in patients with drug-resistant persistent AF can be considered as an alternative to TEE [19]. In our study, the proportion of patients with long-term, persistent, and permanent forms of AF was 12% and 2%, respectively, and during the detection of contrast defects there was no additional acquisition of the LAA. Other studies have shown that the use of an additional, delayed LAA scan improves diagnostic accuracy in the diagnosis of LAA thrombosis when patients lie in prone position. Prone-position CCTA with a delayed scanning phase for detecting intracardiac thrombi was illustrated by Nakamura et al [20]. They demonstrated that, in patients with persistent and long-standing AF prior to catheter ablation, late phase CCTA is an essential technique for the evaluation of intracardiac thrombi and LAA dysfunction [20]. Nevertheless, some patients may not find the prone posture comfortable. The results of studies by Romero et al. showed that biphasic delayed CCTA in the supine position greatly improved the specificity and diagnostic accuracy of imaging to 91% compared to 41% with conventional angiography [21]. Recently Lazoura et al. [22] performed CCTA on 122 patients in a supine position undergoing surgery for arrhythmias and found a 100% predictive value using a delayed scan confirmed by TEE.

Kashtanova Yu. et al reviewed LAA CCTA techniques for interventional treatment of AF [23]. A great emphasis has been placed on minimizing false-positive results of CCTA. Several authors used delayed scanning of 1–5 min after contrast injection to minimize false-positive results [23]. They hypothesized that extending the duration of the investigation enhances the ability to differentiate between blood stasis and thrombosis.

When scanning in the supine position, the LAA lies on a horizontal plane, and in some cases, repeated LAA acquisition is required, and this increases the radiation dose. There is one AF case of cryoballoon ablation using the left lateral decubitus position [24]. In this case, when the patient was in the supine position the LA was compressed by the mildly enlarged aortic root and the vertebra, while the left lateral CCTA demonstrated that the heart can shift forward. Thus, the compression of the LA can be eased in the left lateral decubitus posture [24].

Table 5. Association between sociodemographic and medical characteristics with acute cerebrovascular accident (CVA)

Variable	Without CVA (n=94, 93%)	With CVA (n=7, 7%)	OR (95% CI)[a)]	p-value
Age, yrs	60±11	59±6	0.99 (0.93; 1.07)	0.88
BMI, kg/m^2	30±5.8	31.5±5.3	1.04 (0.92; 1.19)	0.522
CHA_2DS_2-VASc score	1.37±1.22	2.86±1.46	1.12 (1.18; 3.81)	0.012
HAS-BLED score	0.86±0.89	0.86±.69	0.99 (0.41; 2.41)	0.989
CCTA				
LA volume, ml	118.3±34	146.1±18.8	1.02 (1.01; 1.04)	0.046
LA shape				
Cauliflower	25 (27%)	4 (57%)	–	0.102[b)]
Chicken wing	18 (19%)	0	–	0.241[b)]
Windsock	27 (29%)	2 (29%)	–	0.679[b)]
Cactus	24 (25%)	1 (14%)	–	0.445[b)]
Anteroposterior size of the left atrium, cm	4.45±0.8	5.16±0.9	1.78 (1.03; 7.49)	0.044
Transverse dimension of the left atrium, cm	7.29±0.96	7.84±0.71	2.0 (0.79; 5.01)	0.138

Data are mean ± SD or number (%). aUnadjusted rates. b)Fisher's exact test. CVA, cerebrovascular accident; CCTA, cardiac computed tomography angiography; LA, left atrium; OR, odds ratio.

Kaliyev et al. demonstrated the diagnostic accuracy of CCTA in the diagnosis of thrombosis of the LAA in 292 patients with AF from 2012 to 2020 [25]. This study compared the diagnostic accuracy of single and delayed scanning phases for LAA thrombosis in the supine position of patients. The sensitivity and specificity of the CCTA was higher from 2016 to 2020, when the delayed phase had been added to the standard protocol, compared to 2012–2015 (97.7% and 77%, respectively). The positive predictive and negative predictive values of CCTA for detection of the true thrombus were 66.7% and 98%, respectively, for first-pass scans, and 25% and 100% for the delayed scans, respectively [25]. However, to improve the diagnostic accuracy of LAA thrombosis, patients underwent an additional, delayed scanning.

The novel left lateral decubitus scanning technique may be useful for examining the LAA thrombosis in individuals who have musculoskeletal congenital disorders or who are unable to rest on their back due to other medical conditions. Further research is needed in this area. Changing the ratios of the heart chambers in different patient positions may be useful for patients with AF for better visualization of the left atrium and to reduce radiation exposure.

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CHA_2DS_2-VASc, HAS-BLED scores, and LA morphology, volume, and size are correlated in previous studies for risk stratification of LAA thrombus formation and cardioembolism complications [26–32]. An increase in LA volume is a marker of subclinical cardiovascular disease progression and is a predictor of the risk of AF in patients undergoing CCTA [33].

Our study has several limitations. First, it was a single-center study, and to our knowledge, it is the only investigation to have described LA CCTA with the patient in the left lateral position. Furthermore, although the present analysis included 101 patients, there is still a limitation due to their relatively young age and the small number of patients. Second, in our center, measurements of the linear dimensions and volumes of the LV were performed only with TTE. Echocardiograms were gathered from hospital records in the research location, so they were not interpreted systematically; nonetheless, these data reflect actual clinical practice. Third, CCTA with the evaluation of the LA anteroposterior dimension was obtained by measuring on the left lateral decubitus plane, which could need correction, although LA volume does not change despite a change in body position. Finally, to have compared CCTA in different positions for the same patients, imaging of the LAA would have had have been performed multiple times, exposing patients to a substantial, unsafe radiation dosage and contrast administration.

Conclusions

CCTA with the patient positioned on the left side is a valuable screening tool to detect or exclude the presence of LAA thrombus in AF. Moreover, this technique could be used to determine the various risk factors of LAA thrombus presence and of cerebrovascular events. Future studies will aid in further clarifying the diagnostic role of left lateral decubitus CCTA in patients with AF.

Ethics approval and informed consent

The institutional ethics committee approved this study, and it was conducted according to the Declaration of Helsinki. All patients included provided written informed consent.

Consent for publication

Not applicable.

Data availability

The data underlying this article will be shared upon reasonable request to the corresponding author.

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No conflict of interest is reported.

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