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Diagnosis of left atrial appendage thrombus using cardiac computed tomography: new insights from thrombi locations

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Article Title: Diagnosis of left atrial appendage thrombus using cardiac computed tomography: new insights from thrombi locations

Running Head: Detection of Left Atrial Appendage Thrombus Using Cardiac CT

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Abstract

Background Cardiac computed tomography (CCT) is an emerging non-invasive modality for assessing left atrial appendage (LAA) thrombus, but the results were conflicting. Our study aims to evaluate the accuracy of CCT for detecting LAA thrombus in patients undergoing catheter ablation of atrial fibrillation (AF), using transesophageal echocardiography (TEE) as the reference standard.

Methods From May 2017 to December 2022, 726 patients (male: 60.2%, age: 61±11 years) who had both TEE and CCT before catheter ablation of AF were retrospectively included. The CCT protocol consisted of one angiographic phase and one delayed scan 30 seconds later. LAA thrombi were defined as solid masses on TEE or persistent defects on CCT. The thrombus dimension and location, the LAA filling and emptying flow velocity were assessed by TEE. **Results** Of the 57(7.9%) patients with LAA thrombi identified by TEE, 29(50.9%) were located at the LAA ostium, and 28(49.1%) were in the LAA. The former showed higher motility following blood flow and heartbeats than the latter. The CCT detected 14(48.3%) of the LAA-ostium thrombi with the LAA mean flow velocity higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results.

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Conclusion For patients undergoing catheter ablation for AF, CCT with a 30s delay scan is less sensitive to LAA thrombi than TEE, especially for LAA-ostium thrombi with smaller sizes and higher LAA flow velocity.

Keywords stroke; embolism; thrombosis; pulmonary vein isolation; cardiac imaging techniques; ultrasound.

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Strengths and limitations of this study

1. A major strength of our study is based on a large cohort with high incidence of left atrial appendage thrombi.

2. We first report the impact of thrombus location on the sensitivity of CCT, using TEE as

reference standard.

3. A limitation of this study is that it is a single-center and retrospective study.

4. The CCT protocol contained only one delayed-phase scan. Whether multiple delayed-phase scans reduce false-negative CCT results is unclear.

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Title: Diagnosis of left atrial appendage thrombus using cardiac computed tomography: new insights from thrombi locations

Introduction

Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)¹. In the past decades, cardiac computed tomography (CCT) has been widely studied for detecting LAA thrombus²⁻⁵. Recently, the delayed contrast-enhanced CCT at 6 minutes was reported to reach 100% sensitivity and negative predictive value in detecting LAA thrombus⁶. For patients who are not tolerant of the discomfort associated with TEE, CCT is proposed as a reliable alternative⁷. However, the accuracy of CCT varied between studies^{2-5, 8}, raising the safety concern and limiting the routine use of CCT.

The left atrial thrombi were classified into a movable ball, fixed ball, and mountain according to their morphology⁹. Around 1/3 of the thrombi in the left atrium were movable. Although CCT is of high spatial resolution, its temporal resolution is 4~17Hz, and it takes $60\text{ms} \sim 250\text{ms}$ to acquire one slice^{8, 10-12}. Compared to TEE, which allows live display with a high spatiotemporal resolution (<1mm, 20~30Hz)¹³, CCT is theoretically inferior for identifying moving objects in the left atrium. In addition, the circulatory stasis and the fibrillation of the atrial wall during AF also increase the difficulty of detecting movable thrombi¹⁴. In previous studies, the presence of LAA thrombus was 2(0.24%) ~16(19.04%)^{2-5, 15}. The high sensitivity and negative predictive value of CCT could be attributed to the low incidence of movable thrombus. Therefore, it is essential to investigate the diagnostic

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accuracy of CCT in a larger cohort with a higher incidence of LAA thrombus.

In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation for AF. 57(7.9%) patients were diagnosed with LAA thrombi using TEE. We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negative results.

Methods

Study population

From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital. Those who had both examinations within a 12-hour interval on the same day were retrospectively included. All the patient characteristics and images were acquired from the clinical database. The CHA₂DS₂-VASc score was calculated following the 2020 ESC guideline¹. The study was approved by the institutional ethics committee of Guizhou Provincial People's Hospital. The informed consent was waived due to the retrospective nature, and no identified information was collected.

CCT protocol

All patients were examined with a third-generation dual-source CT (SOMATOM Force, Siemens Healthineers, Forchheim, Germany). The imaging protocol included a standard

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angiographic-phase acquisition to assess the anatomy of the left atrium and one delayed-phase acquisition at 30 s after contrast injection to detect thrombi. No electrocardiography gating was used. The tube voltage and current were automatically adjusted using the CARE kV or CARE DOSE 4D with the reference of 100kv and 250mA. The gantry rotation time was 250ms, and the detector collimator was 192×0.6 mm. The scanning image covers the range from the aortic arch to the cardiac base. The monitoring site was localized within the left atrium. The contrast material containing 350 mg/ml of iodine was administrated intravenously at 4-5 ml/s with a total dose of 35 ml by a double-barrel syringe, followed by the same amount of 0.9% saline. For the angiographic phase, the scanning was triggered when the monitoring site reached 90 HU. Then the delayed phase was acquired 30 s later. All images were reconstructed using the ADMIRE algorithm grade 3 with a layer thickness of 1 mm and interlayer spacing of 0.7 mm. The 3D left atrium and pulmonary veins were reconstructed using the Syngo.via software (Siemens Healthcare, Forchheim, Germany).

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CCT image analysis

Images were transferred to an external workstation (Syngo VPCT body, Siemens Healthcare, Forchheim, Germany). Two independent radiologists with more than eight years of cardiovascular imaging, blinded to all patients' data, retrospectively evaluated the presence of LAA thrombus and LAA morphology. Thrombus was defined as a persistent filling defect in the 30s-delayed scans. The LAA morphology was classified into simple or complex according to their main and branching structures on the 3D reconstructions¹⁶. In case of disagreement, a final joint reading was performed to achieve consensus.

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Transesophageal echocardiology

A PhilipsiEPIQ7C color Doppler ultrasound diagnostic instrument (Philips, Amsterdam, the Netherlands) and an X7-2t probe were used. The left atrium and LAA were scanned using a complete 2D, colored, pulsed, and continuous-wave Doppler echocardiogram according to the EACVI recommendations¹⁷. Thrombi were defined as circumscribed echogenic or echolucent masses distinct from the atrial wall. LAA ostium was defined as within the 5mm range of the junction between the smooth atrial wall and trabeculated LAA. The dimensions and locations of thrombi were assessed if present. The LAA filling and emptying velocity was averaged by ten consecutive measurements of the backward and forward flow rates using the pulsed wave Doppler. LAA mean flow velocity (LAAMFV) was calculated by halving the sum of the LAA filling and emptying velocity. Two independent cardiologists with more than five years of experience in echocardiology evaluated the presence of LAA thrombus and measured the flow velocity. Disagreements were resolved by consensus.

Statistical analysis

Continuous variables were expressed as mean \pm SD deviation. The Student's t-test was used for comparison if normally distributed; otherwise, the Mann-Whitney U test was used. Categorical variables were expressed as frequency (percentage). The Chi-square test was used for comparison if the expected frequency is more than 5; otherwise, Fisher's exact test was used. A two-tailed *p* value of less than 0.05 was considered statistically significant. Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was

 calculated. All statistical analysis was performed using SPSS 26.0.

Results

Patient characteristics

A total of 726 patients (age: 61 ± 11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1). The patients with LAA thrombus had a higher incidence of previous stroke/transient ischemic attack (TIA) and congestive heart failure, larger left atrial size, worse left ventricular function and a higher rate of complex LAA morphology than those without LAA thrombus (p < 0.05) (Table 1).

Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. The clinical characteristics and maximum thrombus diameter were similar between the patients. The thrombi at the LAA ostium were accompanied by higher LAA filling and emptying velocities than those in the LAA (Supplementary material online, Table S1). The former also showed significantly higher mobility following the blood flow and cardiac motion than the latter (Supplementary material online, Video S1).

Diagnostic accuracy of CCT

The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% to the LAA thrombi (Table 1). However, the CCT was less sensitive to the thrombi at LAA ostium than those in the LAA (48.3% vs. 89.3%, p = 0.001) (Supplementary material online, Table S1).

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Representative images are shown in Fig. 2.

Given that high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thrombi underwent further analysis. Compared with the CCT true-positive thrombi, the false-negative ones more frequently located at the LAA ostium (83.3% vs. 35.9%, p = 0.001), were shorter in the maximum diameters (8±2mm vs. 14±9mm, p < 0.001), and were accompanied by higher LAA filling and emptying velocities (0.53±0.15 m/s vs. 0.38±0.19 m/s, p = 0.001; 0.55±0.21 m/s vs. 0.37±0.14 m/s, p < 0.001) (Table 2). By scattering the CCT results on the 2-D plane that consisted of LAAMFV and thrombus maximum diameter, the thrombi at the LAA ostium with the LAAMFVs higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results (Fig. 3A). The CCT false-negative thrombi in the LAA had maximum diameters shorter than 8mm (Fig. 3B).

Discussion

Major findings

rian. We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF. TEE identified 57(7.9%) patients with LAA thrombi, of which 29(50.9%) were at the LAA ostium and 28(49.1%) in the LAA. The CCT was less sensitive in detecting LAA-ostium thrombi with smaller maximum diameters and higher LAAMFV.

 LAA thrombus is thought to form initially inside the LAA, where circulatory stasis is the greatest, and then extends towards the ostium. However, we found over half of the thrombi located at the LAA ostium. The result was concordant with a previous study that 46.3% of the thrombi were at the entrance section of LAA⁹. The presence of pits and troughs adjacent to the LAA orifice was reported in 57.7% of the human heart specimens¹⁸. It could be the anatomic basis for thrombosis. Another study using TEE discovered small recesses proximal to the entry of LAA in a significant number of patients, but no thrombus related to these structures was detected following LAA occlusion¹⁹. The discrepancy could be due to patient selection bias. Nonetheless, our findings raised concerns about the role of LAA-ostium recesses in thrombosis.

Although the third-generation 64-slice dual-source CT was employed in the current study, its sensitivity to LAA thrombi was not improved. The sensitivity of 89.3% to the thrombi in the LAA was comparable to the previous studies^{2, 10, 11, 20-22}. However, the sensitivity significantly decreased for the LAA-ostium thrombi, which showed higher motility following blood flow and heartbeats than those in the LAA (Supplementary material online, Video S1). We further identified that the LAA-ostium thrombi with smaller sizes and higher LAA flow velocity were more prone to be missed using the CCT. As a higher temporal resolution is essential to detect movable objects²³, our findings suggested the impact of thrombus motility on CCT imaging. By calculating the gantry rotation time of 250ms, the CCT had a temporal resolution of 4Hz, significantly less than that of the TEE (20–40Hz). Thus, the low sensitivity of CCT in our study could be presumed to: (1) inadequate temporal

resolution, (2) the high proportion of movable LAA-ostium thrombi, (3) the lack of ECG gating, (4) only one 30s delayed scan was used. The 4 CCT false-positive results in our study could be the misdiagnosis of thrombus due to circulatory stasis during AF^{6, 24}.

Discordance

 Several studies reported that the CCT had 100% sensitivity in detecting LAA thrombi using ECG gating and single-segment reconstruction algorithm^{25, 26}, or multiple delayed-phase scans^{3, 14, 27}. However, these studies have the following limitations: (1) Although the single-segment reconstruction algorithm increased the CCT's temporal resolution to 12Hz, the low incidence of LAA thrombus [2(0.24%) ~16(19.04%)] and the less variation of thrombus location could have overestimated the sensitivity of CCT for detecting LAA thrombi in a broader range of patients. (2) The multiple delayed-phase scans distinguished the thrombi from filling defects due to circulatory stasis. Still, the technique could not necessarily increase the sensitivity to smaller and movable thrombi located at the LAA ostium. We suggest that the CCT approach to detect LAA thrombi could differ according to their location. For static thrombi in LAA, persistent filling defects in multiple delayed-phase scans have been well established. For thrombi at LAA ostium, a temporal resolution comparable to TEE and even dynamic visualization could be necessary due to their higher motility.

Clinical implication

Our study found that the CCT with a 30s delayed scan did not reliably exclude LAA thrombus, especially those located at the LAA ostium. We did not find any clinical

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characteristics associated with the thrombus location. TEE is the only recommendation for stroke risk management for patients undergoing catheter ablation of AF in the 2020 ESC guideline¹. For those who do not tolerate TEE, intracardiac echocardiography could be considered²⁸.

Limitations

Firstly, this retrospective single-center study included only patients undergoing catheter ablation for AF. The study's findings may not be generalizable to other patients with AF. Secondly, the CCT protocol contained only one delayed-phase scan. Whether multiple delayed-phase scans reduce false-negative CCT results is unclear. Thirdly, other factors unaccounted for in this analysis – heart rhythm, atrial/ventricular rate, and blood pressure during the TEE and CCT – could affect the conclusions. Fourthly, although the interval between the TEE and CCT was less than 12 hours, it is theoretically possible for thrombi to form or disappear within this timeframe. Lastly, the incidence of LAA thrombus was higher than that in previous studies (partially due to less adherence to anticoagulation treatment), which could have affected the thrombus location and motility.

Conclusions

In patients undergoing catheter ablation of AF, CCT with a 30s delay scan is less sensitive than TEE in detecting LAA thrombi, especially those located at LAA ostium with smaller sizes and higher LAA flow velocity.

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Data sharing statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Ethical approval

This study received approval from the institutional ethics committee of Guizhou Provincial People's Hospital.

Contributors

Chuxian Guo and Zhi Jiang: Conceptualization, Methodology, Formal analysis, Writingoriginal draft, Writing – review & editing. Jionghong He, Haiyan Ma and Yuquan Wang: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing.

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Jing Tan: Conceptualization, Methodology, Investigation, Writing – review & editing. Qiaoqiao Ou: Conceptualization, Investigation, Writing – review & editing. Ye Tian and Qifang Liu: Conceptualization, Writing – review & editing, Funding acquisition. Longhai Tian and Jing Huang: Conceptualization, Investigation, Writing – review & editing. Long Yang: Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision, Funding acquisition. All authors read and approved the final manuscript.

Declaration of Competing Interest The authors declare that they have no competing interests.

Supplementary Material

Video S1 The online supplementary Video S1 showed LAA thrombi imaging of different location in TEE

A-C Thrombus located at the LAA ostium. D-F Thrombus located in the LAA.

 Table S1 Patient characteristics between thrombus locations.

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Figure 1 Patient flowchart.

Abbreviations: AF = atrial fibrillation; CCT = cardiac computed tomography; LAA = left atrial appendage; TEE = transesophageal echocardiography.

Figure 2 Representative TEE and CCT images of the LAA thrombi.

The upper panel shows CCT images. The lower panel shows TEE images. A-B. Representative false-negative CCT result. The thrombus was located in the LAA. C-D. Representative false-negative CCT result. The thrombus was located at the LAA ostium. E-F. Representative true-positive CCT result. The thrombus was located in the LAA. G-H. Representative true-positive CCT result. The thrombus was located at the LAA ostium. White arrows denote the thrombi.

Figure 3 Scatter plots of CCT results of LAA thrombi.

Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. The CCT false-positive thrombi at the LAA ostium had the LAAMFV over 0.35 m/s and the maximum diameters over 10 mm. B. The CCT false-positive thrombi in the LAA ostium had a maximum diameter over 8 mm.

Abbreviations: CCT = cardiac computed tomography; LAA = left atrial appendage;

LAAMFV = left atrial appendage mean flow velocity.

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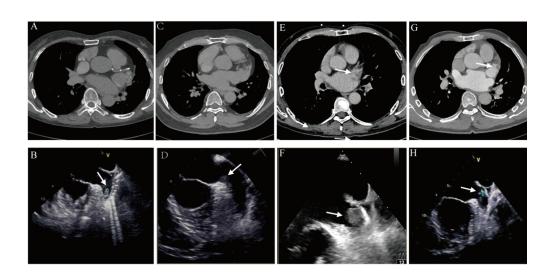
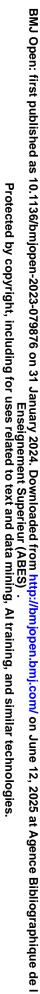
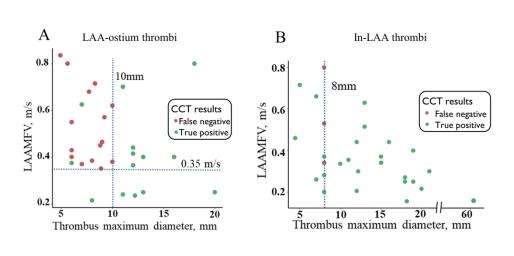


Figure 2 Representative TEE and CCT images of the LAA thrombi.

The upper panel shows CCT images. The lower panel shows TEE images. A-B. Representative false-negative CCT result. The thrombus was located in the LAA. C-D. Representative false-negative CCT result. The thrombus was located at the LAA ostium. E-F. Representative true-positive CCT result. The thrombus was located in the LAA. G-H. Representative true-positive CCT result. The thrombus was located at the LAA ostium. White arrows denote the thrombi.

190x98mm (300 x 300 DPI)







Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. The CCT false-positive thrombi at the LAA ostium had the LAAMFV over 0.35 m/s and the maximum diameters over 10 mm. B. The CCT false-positive thrombi in the LAA ostium had a maximum diameter over 8 mm. Abbreviations: CCT = cardiac computed tomography; LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity.

190x89mm (300 x 300 DPI)

Table 1 Patient characteristics.

		LAA thrombu	us *	
Characteristics	Overall (n=726)	Positive (n=57)	Negative (n=669)	<i>P</i> value
Age, year	61±11	64±10	61±11	0.129
Male	437(60.2)	36(63.2)	401(59.9)	0.634
Paroxysmal AF	436(60.1)	30(52.6)	406(60.7)	0.233
AF course, month	42±83	39±45	43±85	0.540
CHA ₂ DS ₂ -VASc score	2±2	3±2	2±2	0.089
Congestive heart failure	116(16.0)	18(31.6)	98(14.6)	0.001
Hypertension	346(47.7)	25(43.9)	321(48.0)	0.550
Diabetes mellitus	107(14.7)	10(17.5)	97(14.5)	0.534
Previous Stroke/TIA	91(12.5)	14(24.6)	77(11.5)	0.004
Vascular disease	292(40.2)	22(38.6)	270(40.4)	0.795
LAAPD, mm	36±7	41±9	36±7	< 0.001
LVEDD, mm	46±5	49±7	46±5	0.006
LVEF, %	60±8	56±11	60±7	0.005
Complex LAA morphology	289(39.8)	35(61.4)	254(38.0)	0.001
CCT results				
Filling defects	43(5.9)	39(68.4)	4(0.6)	
No filling defects	683(94.1)	18(31.6)	665(99.4)	< 0.001

Values are mean \pm SD or n (%).

* The thrombi were detected using the TEE.

Abbreviations: AF = atrial fibrillation; CCT = cardiac computed tomography; CHA_2DS_2 -VASc = congestive heart failure, hypertension, age \geq 75 years (doubled), diabetes, previous stroke/transient ischemic

attack/thromboembolism (doubled), vascular disease, age 65-74 years and sex category (female); LAA = left

atrial appendage; LAAPD = left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic

diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

	LAA thr	rombus *	
Characteristics	CCT false-negative result	CCT true-positive result	<i>P</i> value
	(n=18)	(n=39)	
Age, years	64±9	64±10	0.810
Male	11(61.1)	25(64.1)	0.828
Paroxysmal AF	12(66.7)	18(46.2)	0.149
AF course, month	42±54	38±40	0.952
CHA ₂ DS ₂ -VASc score	3±2	3±2	0.450
Congestive heart failure	5(27.8)	13(33.3)	0.675
Hypertension	10(55.6)	15(38.5)	0.227
Diabetes mellitus	5(27.8)	5(12.8)	0.168
Previous Stroke/TIA	5(27.8)	9(23.1)	0.702
Vascular disease	7(38.9)	15(38.5)	0.975
LAAPD, mm	41±9	41±9	0.770
LVEDD, mm	49±6	49±7	0.336
LVEF, %	59±9	55±12	0.331
Complex LAA	9(50.0)	26(66.7)	0.230
LAA filling velocity, m/s	0.53±0.15	0.38±0.19	0.002
LAA emptying velocity, m/s	0.55±0.21	0.37±0.14	0.001
Thrombi maximum diameter, mm	8±2	14±9	< 0.00
Thrombus location			
LAA ostium	15(83.3)	14(35.9)	0.001
In LAA	3(16.7)	25(64.1)	0.001
Values are mean \pm SD or n (%).			
* The thrombi were detected using the T	EE.		
Abbreviations: AF = atrial fibrillation; C	CCT = cardiac computed tomograph	ny; CHA ₂ DS ₂ -VASc = congestiv	ve heart
failure, hypertension, age \geq 75 years (do	oubled), diabetes, previous stroke/tra	ansient ischemic attack/thrombo	oembolism
(doubled), vascular disease, age 65–74 y	years and sex category (female); LA	AA = left atrial appendage; LAA	APD = left
atrial anterior-posterior diameter; LVED	DD = left ventricular end-diastolic d	iameter; LVEF = left ventricula	r ejection
fraction; TEE = transesophageal echoca	rdiography; TIA = transient ischem	ic attack.	

Table2 Patient characteristics between CCT true-positive and false-negative results.

Table S1 Patient characteristics between thrombus locations.

	Thrombus 1		
Characteristics	LAA ostium (n=29)	In LAA(n=28)	- P value
Age, years	63±10	64±10	0.886
Male	20(69.0)	16(57.1)	0.355
Paroxysmal AF	18(62.1)	12(42.9)	0.146
AF course, month	40±52	39±35	0.648
CHA ₂ DS ₂ -VASc score	2±2	3±2	0.220
Congestive heart failure	9(31.0)	9(32.1)	0.928
Hypertension	10(34.5)	15(53.6)	0.147
Diabetes mellitus	5(17.2)	5(17.9)	1.000
Previous Stroke/TIA	7(24.1)	7(25.0)	0.940
Vascular disease	9(31.0)	13(46.4)	0.233
LAAPD, mm	41±10	40±8	0.873
LVEDD, mm	49±6	49±8	0.492
LVEF, %	57±11	55±11	0.424
Complex LAA	17(58.6)	18(64.3)	0.661
LAA filling velocity, m/s	0.48±0.19	0.37±0.19	0.021
LAA emptying velocity, m/s	0.47 ± 0.20	0.38±0.16	0.050
Thrombus maximum diameter, mm	10±4	14±10	0.045
CCT results			
Filling defects	14(48.3)	25(89.3)	0.001
No filling defects	15(51.7)	3(10.7)	0.001

Values are mean \pm SD or n (%).

* The thrombus locations were determined using the TEE.

Abbreviations: AF = atrial fibrillation; $CCT = cardiac computed tomography; <math>CHA_2DS_2$ -VASc = congestive heart failure, hypertension, age ≥ 75 years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAPD= left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack. 3 4

nt—che	BMJ Open ecklist of items that should be included in reports of observational studies	by copyright, inclu	1 iopen-2023-07987	Pag
Item No.	Recommendation	ding fo	Page Mage No.	Relevant text from manuscript
1	(<i>a</i>) Indicate the study's design with a commonly used term in the title or the abstract	Enseignement Sup r uses related to text	January 2024. Down	From May 2017 to December 2022, 726 patients (male: 60.2%, age: 61±11 years) who had both TEE and CCT before catheter ablation of AF were retrospectively included.
	(b) Provide in the abstract an informative and balanced summary of what was done and what was found	erieur (ABES) . añð data mining, Al training,	hr-//bmionen.bi	Our study aims to evaluate the accuracy of CCT for detecting LAA thrombus in patients undergoing catheter ablation of atrial fibrillation (AF), using transesophageal echocardiography (TEE) as the reference standard.
2	Explain the scientific background and rationale for the investigation being reported	Similar technologies.	om/ on June 12, 2025 at	Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)
3	State specific objectives, including any prespecified hypotheses	5	nce	We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negative
	<u>Item</u> No. 1	nt—checklist of items that should be included in reports of observational studies Image: Item No. Recommendation 1 (a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found 2 Explain the scientific background and rationale for the investigation being reported	Item No. Recommendation 1 (a) Indicate the study's design with a commonly used term in the title or the abstract Image: Comparison of the commonly of the commonly of the commonly of the common of th	1 (a) Indicate the study's design with a commonly used term in the title or the abstract The Enseignment Superiour (ABES) - Component (ABES) - Component (ABES) - Component (ABES) - Compon

	BMJ Open BMJ Open 	results.
Methods	6 876 a ud	
Study design	4 Present key elements of study design early in the paper 4 Present key elements of study design early in the paper 4 Enseignement 4 Cluding for uses related to	All the patient characteristics and images were acquired from the clinical database. The CHA2DS2-VASc score was calculated following the 2020 ESC guideline.
Setting	 5 Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection 5 Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection 	From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital. Those who had both examinations within a 12-hour interval on the same day were retrospectively included.
Participants	6 (a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up for the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls for the eligibility criteria, and the sources and methods of selection of participants. Describe the eligibility criteria, and the sources and methods of selection of controls for the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participants for the eligibility criteria, and the sources and methods of selection of participan	In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation fo AF.
Variables	 Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. 6,7 G Give diagnostic criteria, if applicable 	Thrombus was defined as a persistent filling defect in the 30s-delayed scans. The LAA morphology was classified into

		BMJ Open	njopen-2023 by copyrigh	Ρ
			njopen-2023-079876 on 31 J 3 by copyright, including for	simple or complex according to their main and branching structures on the 3D reconstructions
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	January 2024. Downloaded from ^r Enseignement Superieur (ABI r uses related to text and data m	All patients were examined wi a third-generation dual-source CT. The imaging protocol included a standard angiographic-phase acquisition to assess the anatomy of the le atrium and one delayed-phase acquisition at 30 s after contrast injection to detect thrombi
Bias	9	Describe any efforts to address potential sources of bias	n http://bmjopen.bmj.com/ on June 12, 2025 3E\$) . ninmg, Al training, and similar technologies.	Two independent radiologists with more than eight years of cardiovascular imaging, blinde to all patients' data Two independent cardiologists with more than five years of experience in echocardiology evaluated the presence of LAA thrombus and measured the flow velocity
Study size	10	Explain how the study size was arrived at	12, 2025 at Agence notogies.	In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation f AF.
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of 33		BMJ Open	n jopen-2023-	
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	3-079876 on 31	Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was calculated.
Statistical methods	12	(<i>a</i>) Describe all statistical methods, including those used to control for confounding	<u>د</u>	Continuous variables were expressed as mean ± SD deviation
		(b) Describe any methods used to examine subgroups and interactions	enne Pinje	
		(c) Explain how missing data were addressed	₩ VAS	
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed		Using TEE as the reference
		<i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed	ade	standard, the diagnostic
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling	nloaded from I Superieur (ABE	performance of CCT for LAA
		strategy	BE BE	thrombi was calculated.
		(<u>e</u>) Describe any sensitivity analyses		
Results		9, A	.//b	
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined	njo	A total of 726 patients (age: 61=
		(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	njopen.bmj.com/	years; male gender: 60.2%) with
		, D	.bm	57(7.9%) LAA thrombi diagnos
			j.co	by TEE were included in the
			D.	study
		(b) Give reasons for non-participation at each stage	√Ą	
		(c) Consider use of a flow diagram	une	A total of 726 patients (age: 61=
		out	÷ 12,	years; male gender: 60.2%) with
			, 2025	57(7.9%) LAA thrombi diagnos
		o o	25 a	by TEE were included in the stu
			IT A	(Fig. 1)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on	yend	A total of 726 patients (age: 61-
		exposures and potential confounders	е́Е	years; male gender: 60.2%) with
			3ibli	57(7.9%) LAA thrombi diagnos
			ogr	by TEE were included in the stu
			aph	(Fig. 1)
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		BMJ Open by coppen- copyri 20:	Page
		BMJ Open BMJ Open (b) Indicate number of participants with missing data for each variable of interest (c) Cohort study—Summarise follow-up time (eg, average and total amount)	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1).
		(c) Cohort study—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	
		Cohort study—Report numbers of outcome events or summary measures over time Case-control study—Report numbers in each exposure category, or summary measures of exposure data mining, Al tra-	Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. Compared with the CCT true- positive thrombi, the false-negative ones more frequently located at the LAA ostium (83.3% vs. 35.9%, p = 0.001)
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	
Main results	16	Cross-sectional study—Report numbers of outcome events or summary measures Image: Cross-sectional study—Report numbers of outcome events or summary measures (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included Image: Cross-sectional study—Report numbers of outcome events or summary measures (b) Report category boundaries when continuous variables were categorized Image: Cross-sectional study—Report numbers of outcome events or summary measures (b) Report category boundaries when continuous variables were categorized Image: Cross-sectional study = Cross-sectional stud	Given that high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA
		at Agen	thrombi underwent further analysis. By scattering the CCT results on the 2-D plane, the thrombi at the LAA ostium
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time N/A_{P}^{Q}	
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Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	njopen-2023-079876 on 31 January 202 9 Enseigne 1 by copyright, ^{An} cluding for uses relate	The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% Given that high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thromb underwent further analysis
Discussion			24. I eme ted t	
Key results	18	Summarise key results with reference to study objectives	Downloaded from the Superieur (<i>L</i> to Text and data	We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	om http://bmjop ABES) . a mining, Al tra	Firstly, this retrospective single- center study included only patients undergoing catheter ablation for AF
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	<mark>pבח.bmj.cc</mark> ס, ווחזחg, and	Thus, the low sensitivity of CCT in our study could be presumed to: (1) inadequate temporal resolution
Generalisability	21	Discuss the generalisability (external validity) of the study results	Al training, and similar technologies.	This retrospective single-center study included only patients undergoing catheter ablation for AF. The study's findings may not be generalizable to other patients with AF
Other informati	ion		at A	
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Agence Bibliogra	This study has received funding from the Science and Technology Support plan of Guizhou Province
		For peer review only - http://bmjopen.bmj.com/site/about/guidelines.x	aphique html de	

BMJ Open *Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in generative and cross-sectional studies. Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE Lad gives methodo. In the Web sites of PLoS M. Incom/). Information on the STROBE. Information on the STROBE. Information on the STROBE. Information on the STROBE. checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Inter http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.stronge-statement.org.

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Diagnosis of left atrial appendage thrombus using cardiac computed tomography: new insights from thrombi locations

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Primary Subject Heading :	Cardiovascular medicine
Secondary Subject Heading:	Cardiovascular medicine, Radiology and imaging
Keywords:	Stroke < NEUROLOGY, Ultrasound < RADIOLOGY & IMAGING, Computed tomography < RADIOLOGY & IMAGING, Thromboembolism < CARDIOLOGY
Note: The following files were s You must view these files (e.g.	ubmitted by the author for peer review, but cannot be converted to PDF. movies) online.
Supplementary material_Video	S1.mp4

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37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

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Keliezony

Running Head: Detection of Left Atrial Appendage Thrombus Using Cardiac CT

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Abstract

Background Cardiac computed tomography (CCT) is an emerging non-invasive modality for assessing left atrial appendage (LAA) thrombus, but the results were conflicting. Our study aims to evaluate the accuracy of CCT for detecting LAA thrombus in patients undergoing catheter ablation of atrial fibrillation (AF), using transesophageal echocardiography (TEE) as the reference standard.

Methods From May 2017 to December 2022, 726 patients (male: 60.2%, age: 61±11 years) who had both TEE and CCT before catheter ablation of AF were retrospectively included. The CCT protocol consisted of one angiographic phase and one delayed scan 30 seconds later. LAA thrombi were defined as solid masses on TEE or persistent defects on CCT. The thrombus dimension and location, the LAA filling and emptying flow velocity were assessed by TEE. **Results** Of the 57(7.9%) patients with LAA thrombi identified by TEE, 29(50.9%) were located at the LAA ostium, and 28(49.1%) were in the LAA. The former showed higher motility following blood flow and heartbeats than the latter. The CCT detected 14(48.3%) of the LAA-ostium thrombi with the LAA mean flow velocity higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results.

Conclusion For patients undergoing catheter ablation for AF, CCT with a 30s delay scan is less sensitive to LAA thrombi than TEE, especially for LAA-ostium thrombi with smaller sizes and higher LAA flow velocity.

Keywords stroke; embolism; thrombosis; pulmonary vein isolation; cardiac imaging techniques; ultrasound.

Strengths and limitations of this study

1. A major strength of our study is based on a large cohort with high incidence of left atrial

appendage thrombi.

2. We first report the impact of thrombus location on the sensitivity of CCT, using TEE as

reference standard.

3. A limitation of this study is that it is a single-center and retrospective study.

4. The CCT protocol contained only one delayed-phase scan. Whether multiple delayed-phase scans reduce false-negative CCT results is unclear.

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Title: Diagnosis of left atrial appendage thrombus using cardiac computed tomography: new insights from thrombi locations

Introduction

 Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)[1]. In the past decades, cardiac computed tomography (CCT) has been widely studied for detecting LAA thrombus[2-5]. Recently, the delayed contrast-enhanced CCT at 6 minutes was reported to reach 100% sensitivity and negative predictive value in detecting LAA thrombus[6]. For patients who are not tolerant of the discomfort associated with TEE, CCT is proposed as a reliable alternative[7]. However, the accuracy of CCT varied between studies[2-5, 8], raising the safety concern and limiting the routine use of CCT.

The left atrial thrombi were classified into a movable ball, fixed ball, and mountain according to their morphology[9]. Around 1/3 of the thrombi in the left atrium were movable. Although CCT is of high spatial resolution, its temporal resolution is 4~17Hz, and it takes 60ms ~ 250ms to acquire one slice[8, 10-12]. Compared to TEE, which allows live display with a high spatiotemporal resolution (<1mm, 20~30Hz)[13], CCT is theoretically inferior for identifying moving objects in the left atrium. In addition, the circulatory stasis and the fibrillation of the atrial wall during AF also increase the difficulty of detecting movable thrombi[14]. In previous studies, the presence of LAA thrombus was 2(0.24%) ~16(19.04%)[2-5, 15]. The high sensitivity and negative predictive value of CCT could be attributed to the low incidence of movable thrombus. Therefore, it is essential to investigate

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the diagnostic accuracy of CCT in a larger cohort with a higher incidence of LAA thrombus. In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation for AF. 57(7.9%) patients were diagnosed with LAA thrombi using TEE. We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negative results.

Methods

Study population

From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital. Those who had both examinations within a 12-hour interval on the same day were retrospectively included. All the patient characteristics and images were acquired from the clinical database. The CHA₂DS₂-VASc score was calculated following the 2020 ESC guideline[1]. The study was approved by the institutional ethics committee of Guizhou Provincial People's Hospital. The informed consent was waived due to the retrospective nature, and no identified information was collected.

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CCT protocol

All patients were examined with a third-generation dual-source CT (SOMATOM Force, Siemens Healthineers, Forchheim, Germany). The imaging protocol included a standard

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angiographic-phase acquisition to assess the anatomy of the left atrium and one delayed-phase acquisition at 30 s after contrast injection to detect thrombi. No electrocardiography gating was used. The tube voltage and current were automatically adjusted using the CARE kV or CARE DOSE 4D with the reference of 100kv and 250mA. The gantry rotation time was 250ms, and the detector collimator was 192×0.6 mm. The scanning image covers the range from the aortic arch to the cardiac base. The monitoring site was localized within the left atrium. The contrast material containing 350 mg/ml of iodine was administrated intravenously at 4-5 ml/s with a total dose of 35 ml by a double-barrel syringe, followed by the same amount of 0.9% saline. For the angiographic phase, the scanning was triggered when the monitoring site reached 90 HU. Then the delayed phase was acquired 30 s later. All images were reconstructed using the ADMIRE algorithm grade 3 with a layer thickness of 1 mm and interlayer spacing of 0.7 mm. The 3D left atrium and pulmonary veins were reconstructed using the Syngo.via software (Siemens Healthcare, Forchheim, Germany).

CCT image analysis

Images were transferred to an external workstation (Syngo VPCT body, Siemens Healthcare, Forchheim, Germany). Two independent radiologists with more than eight years of cardiovascular imaging, blinded to all patients' data, retrospectively evaluated the presence of LAA thrombus and LAA morphology. Thrombus was defined as a persistent filling defect in the 30s-delayed scans. The LAA morphology was classified into simple or complex according to their main and branching structures on the 3D reconstructions[16]. In case of disagreement, a final joint reading was performed to achieve consensus.

Transesophageal echocardiology

A PhilipsiEPIQ7C color Doppler ultrasound diagnostic instrument (Philips, Amsterdam, the Netherlands) and an X7-2t probe were used. The left atrium and LAA were scanned using a complete 2D, colored, pulsed, and continuous-wave Doppler echocardiogram according to the EACVI recommendations[17]. Thrombi were defined as circumscribed echogenic or echolucent masses distinct from the atrial wall. LAA ostium was defined as within the 5mm range of the junction between the smooth atrial wall and trabeculated LAA. The dimensions and locations of thrombi were assessed if present. The LAA filling and emptying velocity was averaged by ten consecutive measurements of the backward and forward flow rates using the pulsed wave Doppler. LAA mean flow velocity (LAAMFV) was calculated by halving the sum of the LAA filling and emptying velocity. Two independent cardiologists with more than five years of experience in echocardiology evaluated the presence of LAA thrombus and measured the flow velocity. Disagreements were resolved by consensus.

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Statistical analysis

Continuous variables were expressed as mean \pm SD deviation. The Student's t-test was used for comparison if normally distributed; otherwise, the Mann-Whitney U test was used. Categorical variables were expressed as frequency (percentage). The Chi-square test was used for comparison if the expected frequency is more than 5; otherwise, Fisher's exact test was used. A two-tailed *p* value of less than 0.05 was considered statistically significant. Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was

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calculated. Multivariate logistic regression analysis was conducted to determine the predictors of CCT false-negative results, and the validity was assessed using the receiver operating characteristics (ROC) curve. All statistical analysis was performed using SPSS 26.0.

Results

Patient characteristics

A total of 726 patients (age: 61 ± 11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Figure 1). The patients with LAA thrombus had a higher incidence of previous stroke/transient ischemic attack (TIA) and congestive heart failure, larger left atrial size, worse left ventricular function, and a higher rate of complex LAA morphology than those without LAA thrombus (p < 0.05) (Table 1).

Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. The clinical characteristics and maximum thrombus diameter were similar between the patients. The thrombi at the LAA ostium were accompanied by higher LAA filling and emptying velocities than those in the LAA (Supplementary material online, Table S1). The former also showed significantly higher mobility following the blood flow and cardiac motion than the latter (Supplementary material online, Video S1).

Diagnostic accuracy of CCT

The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% to the LAA

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thrombi (Table 1). However, the CCT was less sensitive to the thrombi at LAA ostium than those in the LAA (48.3% vs. 89.3%, p = 0.001) (Supplementary material online, Table S1). Representative images are shown in Figure 2.

Given that a high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thrombi underwent further analysis. Compared with the CCT true-positive thrombi, the false-negative ones more frequently located at the LAA ostium (83.3% vs. 35.9%, p =0.001), were shorter in the maximum diameters (8 ± 2 mm vs. 14 ± 9 mm, p < 0.001), and were accompanied by higher LAA filling and emptying velocities (0.53±0.15 m/s vs. 0.38±0.19 m/s, p = 0.001; 0.55±0.21 m/s vs. 0.37±0.14 m/s, p < 0.001) (Table 2). The result was also concordant in the LAA-ostium thrombi subgroup (Supplementary material online, Table S2). By scattering the CCT results on the 2-D plane that consisted of LAAMFV and thrombus maximum diameter, the thrombi at the LAA ostium with the LAAMFVs higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results (Figure 3A). For the thrombi in the LAA, the maximum diameter or LAAMFV did not impact the CCT results (Figure 3B). In the logistic regression model, the thrombus maximum diameter, location, and LAA mean flow velocity (LAAMFV) were independently associated with the CCT false-negative results (Supplementary material online, Table S3). The ROC curve (AUC 0.909, 95%CI: 0.834 ~ 0.984) is shown in Figure S1.

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Discussion

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We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF. TEE identified 57(7.9%) patients with LAA thrombi, of which 29(50.9%) were at the LAA ostium and 28(49.1%) in the LAA. The CCT was less sensitive in detecting LAA-ostium thrombi with smaller maximum diameters and higher

LAAMFV.

Concordance

LAA thrombus is thought to form initially inside the LAA, where circulatory stasis is the greatest, and then extends towards the ostium. However, we found over half of the thrombi located at the LAA ostium. The result was concordant with a previous study in which 46.3% of the thrombi were at the entrance section of LAA[9]. The presence of pits and troughs adjacent to the LAA orifice was reported in 57.7% of the human heart specimens[18]. It could be the anatomic basis for thrombosis. Another study using TEE discovered small recesses proximal to the entry of LAA in a significant number of patients, but no thrombus related to these structures was detected following LAA occlusion[19]. The discrepancy could be due to patient selection bias. Nonetheless, our findings raised concerns about the role of LAA-ostium recesses in thrombosis.

Although the third-generation 64-slice dual-source CT was employed in the current study, its sensitivity to LAA thrombi was not improved. The sensitivity of 89.3% to the thrombi in the LAA was comparable to the previous studies[2, 10, 11, 20-22]. However, the sensitivity significantly decreased for the LAA-ostium thrombi, which showed higher motility

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following blood flow and heartbeats than those in the LAA (Supplementary material online, Video S1). We further identified that the LAA-ostium thrombi with smaller sizes and higher LAA flow velocity were more prone to be missed using the CCT. As a higher temporal resolution is essential to detect movable objects[23], our findings suggested the impact of thrombus motility on CCT imaging. By calculating the gantry rotation time of 250ms, the CCT had a temporal resolution of 4Hz, significantly less than that of the TEE (20~40Hz). Thus, the low sensitivity of CCT in our study could be presumed to: (1) inadequate temporal resolution, (2) the high proportion of movable LAA-ostium thrombi, (3) the lack of ECG gating, (4) only one 30s delayed scan was used. The 4 CCT false-positive results in our study could be the misdiagnosis of thrombus due to circulatory stasis during AF[6, 24].

Discordance

Several studies reported that the CCT had 100% sensitivity in detecting LAA thrombi using ECG gating, single-segment reconstruction algorithm[25, 26], or multiple delayed-phase scans[3, 14, 27]. However, these studies have the following limitations: (1) Although the single-segment reconstruction algorithm increased the CCT's temporal resolution to 12Hz, the low incidence of LAA thrombus [2(0.24%) ~16(19.04%)] and the less variation of thrombus location could have overestimated the sensitivity of CCT for detecting LAA thrombi in a broader range of patients. (2) The multiple delayed-phase scans distinguished the thrombi from filling defects due to circulatory stasis. Still, the technique could not necessarily increase the sensitivity to smaller and movable thrombi at the LAA ostium.

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We suggest that the CCT approach to detect LAA thrombi could differ according to their

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location and motility. Persistent filling defects in multiple delayed-phase scans have been well established for static thrombi in LAA. However, LAA-ostium thrombi could be highly motile due to blood flow and myocardial contraction. In our study, the LAA flow velocity indirectly reflected the thrombus motility. The filling defects that indicate the presence of thrombi could still be enhanced as the thrombi swayed much faster than the duration required for scanning. Furthermore, the filling defect size also depended on the thrombi size. Therefore, smaller LAA-ostium thrombi with higher LAA flow velocity could be prone to be missed by CCT. A temporal resolution comparable to TEE (20~40Hz) could be necessary.

Clinical implication

Our study found that the CCT with a 30s delayed scan did not reliably exclude LAA thrombus, especially those located at the LAA ostium. We did not find any clinical characteristics associated with the thrombus location. TEE is the only recommendation for stroke risk management for patients undergoing catheter ablation of AF in the 2020 ESC guideline[1]. For those who do not tolerate TEE, intracardiac echocardiography could be considered[28].

Limitations

Firstly, this retrospective single-center study included only patients undergoing catheter ablation for AF. The study's findings may not be generalizable to other patients with AF. Secondly, the CCT protocol contained only one delayed-phase scan. Whether multiple delayed-phase scans reduce false-negative CCT results is unclear. Thirdly, other factors

unaccounted for in this analysis – heart rhythm, atrial/ventricular rate, and blood pressure during the TEE and CCT – could affect the conclusions. Fourthly, although the interval between the TEE and CCT was less than 12 hours, it is theoretically possible for thrombi to form or disappear within this timeframe. Lastly, the incidence of LAA thrombus was higher than that in previous studies (partially due to less adherence to anticoagulation treatment), which could have affected the thrombus location and motility.

Conclusions

In patients undergoing catheter ablation of AF, CCT with a 30s delay scan is less sensitive than TEE in detecting LAA thrombi, especially those located at LAA ostium with smaller sizes and higher LAA flow velocity.

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Data sharing statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Ethical approval

This study received approval from the institutional ethics committee of Guizhou Provincial People's Hospital.

Contributors

Chuxian Guo and Zhi Jiang: Conceptualization, Methodology, Formal analysis, Writingoriginal draft, Writing – review & editing. Jionghong He, Haiyan Ma, and Yuquan Wang: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing. Jing Tan: Conceptualization, Methodology, Investigation, Writing – review & editing. Qiaoqiao Ou: Conceptualization, Investigation, Writing – review & editing. Ye Tian and Qifang Liu: Conceptualization, Writing – review & editing, Funding acquisition. Longhai Tian and Jing Huang: Conceptualization, Investigation, Writing – review & editing. Long Yang: Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision, Funding acquisition. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Supplementary Materials

Video S1 Representative TEE video of the thrombi at LAA ostium (A-C) and those in

the LAA (D-F).

Table S1 Patient characteristics between thrombus locations.

Table S2 Patient characteristics between true-positive and false-negative CCT results.

Table S3 Multivariate analysis of the predictors for false-negative CCT results.

Figure S1 The ROC curve of the logistic regression model for predicting false-negative

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CCT results.

Abbreviation: AUC= area under the curve; CCT = cardiac computer tomography; CI =

confidence interval.

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Figure 1 Patient flowchart.

Abbreviations: AF = atrial fibrillation; CCT = cardiac computed tomography; LAA = left atrial appendage; TEE = transesophageal echocardiography.

Figure 2 Representative CCT and TEE images of the LAA thrombi.

The left and middle images are from the CCT angiographic and delayed phase. The right images are from the TEE. A-C. Representative false-negative CCT result of the thrombus in the LAA. D-F. Representative false-negative CCT result of the LAA-ostium thrombus. G-I. Representative true-positive CCT result of the thrombus in the LAA. J-L. Representative true-positive CCT result of the thrombus. White arrows denote the thrombi. Abbreviation: CCT = cardiac computer tomography; LAA = left atrial appendage. Enseignement Superieur (ABES) . Protected by copyright, including for uses related to text and data mining, Al training, and similar technologies.

Figure 3 Scatter plots of CCT results.

Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. For the LAA-ostium thrombi, the CCT false-negative results had the LAAMFV higher than 0.35 m/s and maximum diameters less than 10 mm. B. For the thrombi in the LAA, the maximum diameter or LAAMFV did not significantly impact CCT results. **Abbreviations:** CCT = cardiac computed tomography; LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity.

Table 1 Patient characteristics.

Chamatariatian		LAA t	hrombus *	
Characteristics	Overall (n=726)	Positive (n=57)	Negative (n=669)	<i>P</i> value
Age, year	61±11	64±10	61±11	0.129
Male	437(60.2)	36(63.2)	401(59.9)	0.634
Paroxysmal AF	436(60.1)	30(52.6)	406(60.7)	0.233
AF course, month	42±83	39±45	43±85	0.540
CHA ₂ DS ₂ -VASc score	2±2	3±2	2±2	0.089
Congestive heart failure	116(16.0)	18(31.6)	98(14.6)	0.001
Hypertension	346(47.7)	25(43.9)	321(48.0)	0.550
Diabetes mellitus	107(14.7)	10(17.5)	97(14.5)	0.534
Previous Stroke/TIA	91(12.5)	14(24.6)	77(11.5)	0.004
Vascular disease	292(40.2)	22(38.6)	270(40.4)	0.795
LAAPD, mm	36±7	41±9	36±7	< 0.00
LVEDD, mm	46±5	49±7	46±5	0.006
LVEF, %	<i>▲</i> 60±8	56±11	60±7	0.005
Complex LAA morphology	289(39.8)	35(61.4)	254(38.0)	0.001
CCT results				
Filling defects	43(5.9)	39(68.4)	4(0.6)	< 0.00
No filling defects	683(94.1)	18(31.6)	665(99.4)	< 0.00

Values are mean \pm SD or n (%).

* The thrombi were detected using the TEE.

Abbreviations: AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc =

congestive heart failure, hypertension, age \geq 75 years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAPD = left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

	LAA thr	ombus *	
Characteristics	CCT false-negative result (n=18)	CCT true-positive result (n=39)	P value
Age, years	64±9	64±10	0.810
Male	11(61.1)	25(64.1)	0.828
Paroxysmal AF	12(66.7)	18(46.2)	0.149
AF course, month	42±54	38±40	0.952
CHA ₂ DS ₂ -VASc score	3±2	3±2	0.450
Congestive heart failure	5(27.8)	13(33.3)	0.675
Hypertension	10(55.6)	15(38.5)	0.227
Diabetes mellitus	5(27.8)	5(12.8)	0.168
Previous Stroke/TIA	5(27.8)	9(23.1)	0.702
Vascular disease	7(38.9)	15(38.5)	0.975
LAAPD, mm	<u>41±9</u>	41±9	0.770
LVEDD, mm	49±6	49±7	0.336
LVEF, %	59±9	55±12	0.331
Complex LAA	9(50.0)	26(66.7)	0.230
LAA filling velocity, m/s	0.53±0.15	0.38±0.19	0.002
LAA emptying velocity, m/s	0.55±0.21	0.37±0.14	0.001
Thrombi maximum diameter, mm	8±2	14±9	< 0.001
Thrombus location			
LAA ostium	15(83.3)	14(35.9)	0.001
In LAA	3(16.7)	25(64.1)	0.001

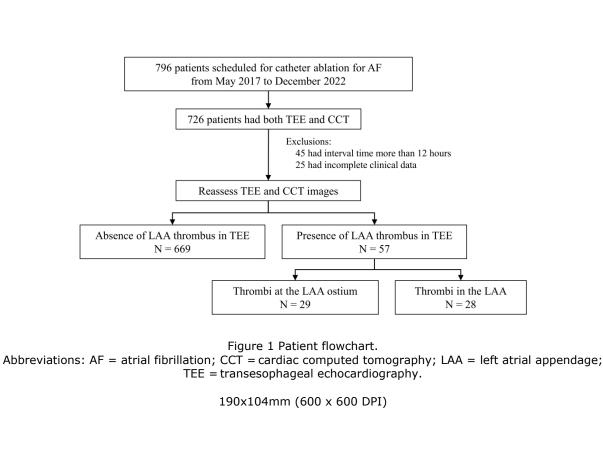
 Table 2 Patient characteristics between CCT true-positive and false-negative results.

Values are mean \pm SD or n (%).

* The thrombi were detected using the TEE.

Abbreviations: AF = atrial fibrillation; $CCT = cardiac computed tomography; <math>CHA_2DS_2$ -VASc = congestive heart failure, hypertension, age ≥ 75 years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAPD = left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.





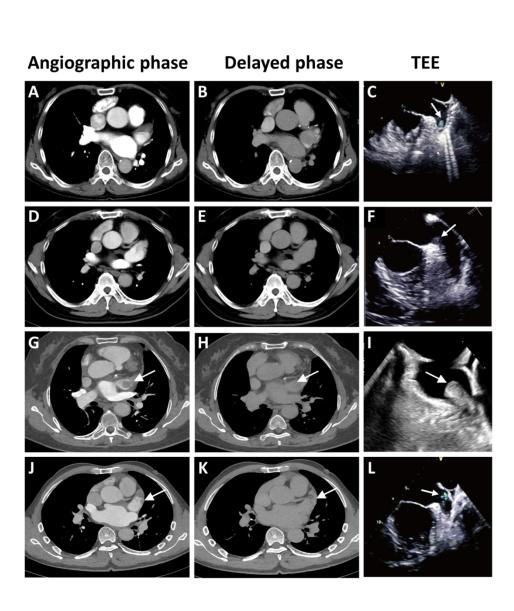


Figure 2 Representative CCT and TEE images of the LAA thrombi.

The left and middle images are from the CCT angiographic and delayed phase. The right images are from the TEE. A-C. Representative false-negative CCT result of the thrombus in the LAA. D-F. Representative false-negative CCT result of the LAA-ostium thrombus. G-I. Representative true-positive CCT result of the thrombus in the LAA. J-L. Representative true-positive CCT result of the LAA-ostium thrombus. White arrows denote the thrombi.

Abbreviation: CCT = cardiac computer tomography; LAA = left atrial appendage.

116x128mm (300 x 300 DPI)



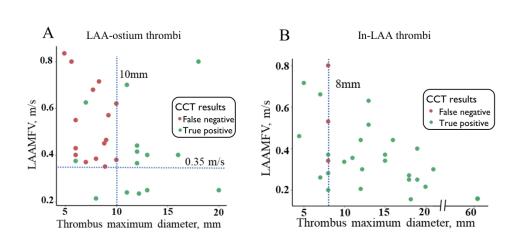


Figure 3 Scatter plots of CCT results.

Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. For the LAA-ostium thrombi, the CCT false-negative results had the LAAMFV higher than 0.35 m/s and maximum diameters less than 10 mm. B. For the thrombi in the LAA, the maximum diameter or LAAMFV did not significantly impact CCT results.

Abbreviations: CCT = cardiac computed tomography; LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity.

190x89mm (600 x 600 DPI)

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Table S1 Patient characteristics between thrombus locations.

	Thrombus lo	ocations *	
Characteristics -	LAA ostium (n=29)	In LAA (n=28)	<i>P</i> value
Age, years	63±10	64±10	0.886
Male	20(69.0)	16(57.1)	0.355
Paroxysmal AF	18(62.1)	12(42.9)	0.146
AF course, month	40±52	39±35	0.648
CHA ₂ DS ₂ -VASc score	2±2	3±2	0.220
Congestive heart failure	9(31.0)	9(32.1)	0.928
Hypertension	10(34.5)	15(53.6)	0.147
Diabetes mellitus	5(17.2)	5(17.9)	1.000
Previous Stroke/TIA	7(24.1)	7(25.0)	0.940
Vascular disease	9(31.0)	13(46.4)	0.233
LAAPD, mm	41±10	40±8	0.873
LVEDD, mm	49±6	49±8	0.492
LVEF, %	57±11	55±11	0.424
Complex LAA	17(58.6)	18(64.3)	0.661
LAA filling velocity, m/s	0.48 ± 0.19	0.37±0.19	0.021
LAA emptying velocity, m/s	0.47 ± 0.20	0.38±0.16	0.050
LAAMFV, m/s	0.47 ± 0.18	0.37±0.17	0.029
Thrombus maximum diameter, mm	10±4	14±10	0.045
CCT results			
Filling defects	14(48.3)	25(89.3)	0.001
No filling defects	15(51.7)	3(10.7)	0.001

Values are mean \pm SD or n (%).

* The thrombus locations were determined using the TEE.

The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. **Abbreviations:** $AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc = congestive heart failure, hypertension, age <math>\geq 75$ years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity; LAAPD= left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

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	LAA-ostiu	m thrombi [*]	
Characteristics	CCT false-negative result	CCT true-positive result	P value
	(n=15)	(n=14)	
Age, years	63±10	64±10	0.726
Male	10(66.7)	10(71.4)	1.000
Paroxysmal AF	10(66.7)	8(57.1)	0.597
AF course, month	44±58	36±45	0.677
CHA ₂ DS ₂ -VASc score	3±2	2±2	0.288
Congestive heart failure	4(26.7)	5(35.7)	0.700
Hypertension	8(53.3)	2(14.3)	0.050
Diabetes mellitus	4(26.7)	1(7.1)	0.330
Previous Stroke/TIA	4(26.7)	3(21.4)	1.000
Vascular disease	6(40.0)	3(21.4)	0.427
LAAPD, mm	39±9	44±11	0.221
LVEDD, mm	49±6	48±5	0.370
LVEF, %	59±8	55±13	0.444
Complex LAA	7(46.7)	10(71.4)	0.264
LAA filling velocity, m/s	0.52±0.15	0.43±0.21	0.110
LAA emptying velocity, m/s	0.55±0.21	0.38±0.15	0.027
LAAMFV, m/s	0.53±0.16	0.41±0.18	0.047
Thrombus maximum diameter, mm	8±2	12±4	0.001

Table S2 Patient characteristics between true-positive and false-negative CCT results.

Values are mean \pm SD or n (%).

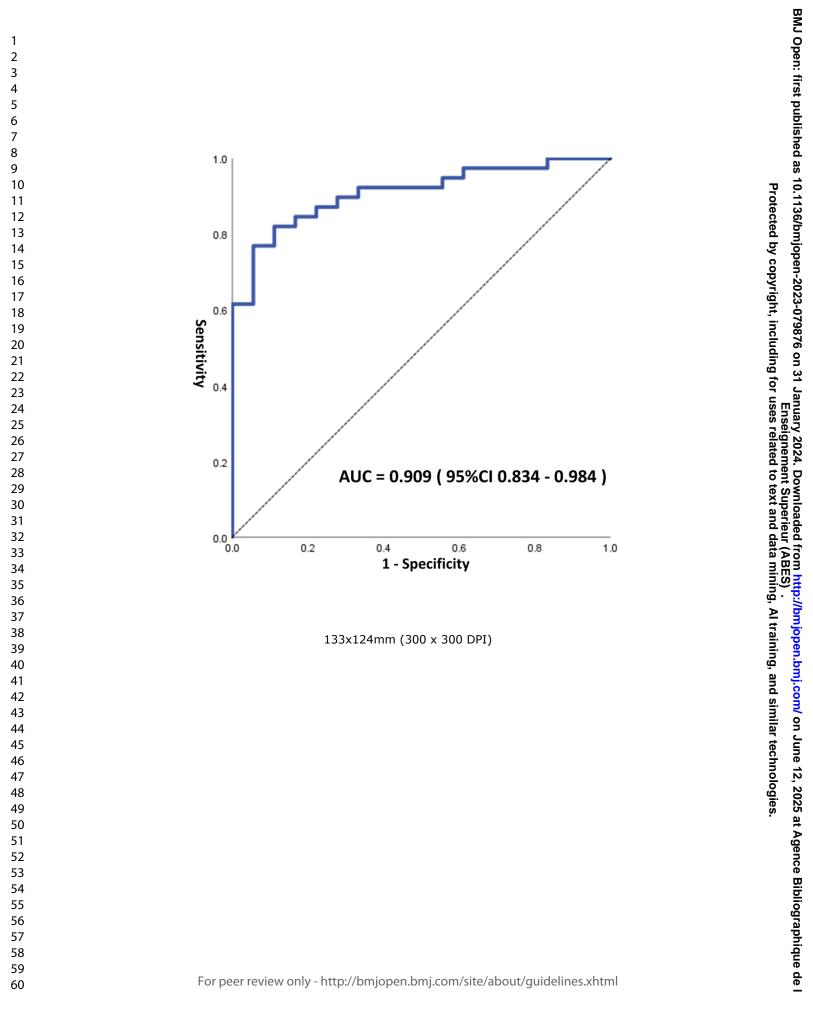
* The LAA-ostium thrombi were determined using the TEE.

The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity.

Abbreviations: $AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc = congestive heart failure, hypertension, age <math>\geq 75$ years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity; LAAPD= left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

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Thrombus maximum diameter, per 1 mm decrease 0.635 (0.459 ~ 0.879) 0.0 LAA-ostium thrombus 10.981 (1.702 ~ 70.831) 0.0 LAAMFV, per 1 m/s increase 47.926 (0.382 ~ 6014.699) 0.1 Abbreviations: CCT = cardiac computer tomography; CI = confidence interval; LAA = 1 appendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.			Characteristics
LAAMFV, per 1 m/s increase 47.926 (0.382 ~ 6014.699) 0.1 Abbreviations: CCT = cardiac computer tomography; CI = confidence interval; LAA = 1 appendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.		0.635 (0.459 ~ 0.879)	Thrombus maximum diameter, per 1 mm decrease
Abbreviations: CCT = cardiac computer tomography; CI = confidence interval; LAA = 1 appendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.	1)	10.981 (1.702 ~ 70.831)	LAA-ostium thrombus
appendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.	699)	47.926 (0.382 ~ 6014.699)	LAAMFV, per 1 m/s increase
appendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.	val; LAA	ny; CI = confidence interval; I	Abbreviations: CCT = cardiac computer tomograp
	l ratio.	flow velocity; OR = odd ratio	ppendage; LAAMFV = left atrial appendage mean



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STROBE Stateme	nt—ch	ecklist of items that should be included in reports of observational studies	inclu	79876	
	Item No.	Recommendation	ding fo	Page Δ No.	Relevant text from manuscript
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	BES) . mining, Al training,	y 2024. Downloaded from http://bmjopen.b	 From May 2017 to December 2022, 726 patients (male: 60.2%, age: 61±11 years) who had both TEE and CCT before catheter ablation of AF were retrospectively included. Our study aims to evaluate the accuracy of CCT for detecting LAA thrombus in patients undergoing catheter ablation of atrial fibrillation (AF), using transesophageal echocardiography (TEE) as the reference standard.
Introduction Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5 ⁵ similar technologies.	mj.com/ on June 12, 2025 at Age	Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)
Objectives	3	State specific objectives, including any prespecified hypotheses	5	ence Bibliographique	We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negative
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		9 	njopen-2023-079876	results.
Methods			ດ - <u>0</u>	
Study design	4		njopen-2023-079876 on 31 January 2024. E Enseigneme	All the patient characteristics and images were acquired from the clinical database. The CHA2DS2-VASc score was calculated following the 2020 ESC guideline.
Setting	5	ita mining,	Downloaded from http://bmjoper ht Superieur (ABES)	From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital. Those who had both examinations within a 12-hour interval on the same day were retrospectively included.
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants (b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case	nbmj.com/ on June 12, 2025 at Age	In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation for AF.
Variables	7		5,7 Bibliographique de	Thrombus was defined as a persistent filling defect in the 30s-delayed scans. The LAA morphology was classified into

BMJ Open 8* For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	simple or complex according to their main and branching structures on the 3D reconstructions All patients were examined with a third-generation dual-source CT. The imaging protocol included a standard
8* For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	a third-generation dual-source CT. The imaging protocol
wnloaded fron Superieur (AE ata r	angiographic-phase acquisition to assess the anatomy of the les atrium and one delayed-phase acquisition at 30 s after contras injection to detect thrombi
9 Describe any efforts to address potential sources of bias Al training, and similar techning in the second	Two independent radiologists with more than eight years of cardiovascular imaging, blinde to all patients' data Two independent cardiologists with more than five years of experience in echocardiology evaluated the presence of LAA thrombus and measured the flow velocity
10 Explain how the study size was arrived at	The flag area and the factor
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_	10 Explain how the study size was arrived at

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Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	ıjopen-2023-079876 on 31 . by copyright, ^m cluding fo	Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was calculated.
Statistical methods	12	(<i>a</i>) Describe all statistical methods, including those used to control for confounding	January 2024, Downloaded from http Enseignement Superieur (ABES) r uses related to text and data minn	Continuous variables were expressed as mean ± SD deviation
		(b) Describe any methods used to examine subgroups and interactions		
		(c) Explain how missing data were addressed		
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed		Using TEE as the reference
		Case-control study—If applicable, explain how matching of cases and controls was addressed	ade	standard, the diagnostic
		Cross-sectional study—If applicable, describe analytical methods taking account of sampling	d fr Jar (/ data	performance of CCT for LAA
		strategy		thrombi was calculated.
		(<u>e</u>) Describe any sensitivity analyses		
Results			g, A	
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	njopen.bmj.com/ on training, and similar	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram	June 12, 2025 at téchnologies.	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Agence Bibliographique de	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1)
		4 For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xht	ique de I	

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	(b) Indicate number of participants with missing data for each variable of interest	njopen-2023-079876 on 31 Janu Ei 4 by copyright, ^a ncluding for us	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1).
	(c) Cohort study—Summarise follow-up time (eg, average and total amount)	nsei es m	
Outcome data	* <u>Cohort study</u> —Report numbers of outcome events or summary measures over time		
	Case-control study—Report numbers in each exposure category, or summary measures of o	y 2024. Downloaded from http://bmjopen.bmj.com/ on June 12, 2025 ; pighement Superieur (ABES) . refated to text and data mining, AI traffing; and similar technologies. recision hey were	Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. Compared with the CCT true- positive thrombi, the false-negativ ones more frequently located at the LAA ostium (83.3% vs. 35.9%, p 0.001)
	Cross-sectional study—Report numbers of outcome events or summary measures		
Main results	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their p (eg, 95% confidence interval). Make clear which confounders were adjusted for and why the included	hey were and sir	
	(b) Report category boundaries when continuous variables were categorized	at Age	Given that high sensitivity is essential to exclude LAA thrombut the CCT results of the LAA thrombi underwent further analysi By scattering the CCT results on the 2-D plane, the thrombi at the LAA ostium
	(c) If relevant, consider translating estimates of relative risk into absolute risk for a meanin period	gful time N/A	
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17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% Given that high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thrombi underwent further analysis
18	Summarise key results with reference to study objectives	ownloaded fro t Superieur (<i>I</i> Text and data	We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF.
19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	om http://bmjo A&ES) . 1 mining, Al tra	Firstly, this retrospective single- center study included only patients undergoing catheter ablation for AF
20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	pgn.bmj.co 0, aintng, and	Thus, the low sensitivity of CCT in our study could be presumed to: (1) inadequate temporal resolution
21	Discuss the generalisability (external validity) of the study results		This retrospective single-center study included only patients undergoing catheter ablation for AF. The study's findings may not be generalizable to other patients with AF
on		7	
22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13 gence Bibliographique de	This study has received funding from the Science and Technology Support plan of Guizhou Province
	18 19 20 21 on	 17 Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses 18 Summarise key results with reference to study objectives 18 Summarise key results with reference to study objectives 19 Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias 20 Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence 21 Discuss the generalisability (external validity) of the study results on 22 Give the source of funding and the role of the funders for the present study and, if applicable, for the 	17 Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses International sensitivity analyses 17 Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses International sensitivity analyses 18 Summarise key results with reference to study objectives International sensitivity analyses 19 Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias International sensitivity of analyses, results from similar studies, and other relevant evidence 20 Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence International sector sec

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 *Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in solo
 and cross-sectional studies.

 Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE

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Impact of left atrial appendage thrombus location on diagnostic accuracy of cardiac computer tomography: a case-control study

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Keywords:	Stroke < NEUROLOGY, Ultrasound < RADIOLOGY & IMAGING, Computed tomography < RADIOLOGY & IMAGING, Thromboembolism < CARDIOLOGY
Note: The following files were s You must view these files (e.g.	submitted by the author for peer review, but cannot be converted to PDF movies) online.
Supplementary material_Video	S1.mp4

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37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

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Article Title: Impact of left atrial appendage thrombus location on diagnostic accuracy of cardiac computer tomography: a case-control study

Running Head: Detection of Left Atrial Appendage Thrombus Using Cardiac CT

Authors: Chuxian Guo ^{ad}*; Zhi Jiang ^a*; Jionghong He ^{ab}; Haiyan Ma ^c; Yuquan Wang ^c; Jing Tan ^{ab}; Qiaoqiao Ou ^{ad}; Ye Tian ^a; Longhai Tian ^a; Qifang Liu ^a; Jing Huang ^a; Long Yang ^a

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Objective Cardiac computed tomography (CCT) is an emerging non-invasive modality for assessing left atrial appendage (LAA) thrombus, but the results were conflicting. Our study aims to evaluate the accuracy of CCT for detecting LAA thrombus in patients undergoing catheter ablation of atrial fibrillation, using transesophageal echocardiography (TEE) as the reference standard.

Design Case-control study.

Setting Patient data were collected from a tertiary hospital in China between 2017 and 2022.Participants The study enrolled 726 patients (male: 60.2%, age: 61±11 years) who had both TEE and CCT before catheter ablation of atrial fibrillation.

Measures The CCT protocol consisted of one angiographic phase and one delayed scan 30 seconds later. LAA thrombi were defined as solid masses on TEE or persistent defects on CCT. The thrombus dimension and location, the LAA filling and emptying flow velocity were assessed by TEE.

Results Of the 57(7.9%) patients with LAA thrombi identified by TEE, 29(50.9%) were located at the LAA ostium, and 28(49.1%) were in the LAA. The former showed higher motility following blood flow and heartbeats than the latter. The CCT detected 14(48.3%) of the LAA-ostium thrombi but 25(89.3%) of those in the LAA (p = 0.001). The LAA-ostium thrombi with the LAA mean flow velocity higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results.

Conclusion For patients undergoing catheter ablation for atrial fibrillation, CCT with a 30s delay scan is less sensitive to LAA thrombi than TEE, especially for LAA-ostium thrombi with smaller sizes and higher LAA flow velocity.

Keywords stroke; embolism; thrombosis; pulmonary vein isolation; cardiac imaging techniques; ultrasound.

Strengths and limitations of this study

1. A major strength of our study is based on a large cohort with high incidence of left atrial appendage thrombi.

2. We first report the impact of thrombus location on the sensitivity of CCT, using TEE as

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reference standard.

3. A limitation of this study is that it is a single-center and retrospective study.

4. The CCT protocol contained only one delayed-phase scan. Whether multiple delayed-phase

scans reduce false-negative CCT results is unclear.

Title: Impact of left atrial appendage thrombus location on diagnostic accuracy of cardiac computer tomography: a case-control study

Introduction

 Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)[1]. In the past decades, cardiac computed tomography (CCT) has been widely studied for detecting LAA thrombus[2-5]. Recently, the delayed contrast-enhanced CCT at 6 minutes was reported to reach 100% sensitivity and negative predictive value in detecting LAA thrombus[6]. For patients who are not tolerant of the discomfort associated with TEE, CCT is proposed as a reliable alternative[7]. However, the accuracy of CCT varied between studies[2-5, 8], raising the safety concern and limiting the routine use of CCT.

The left atrial thrombi were classified into a movable ball, fixed ball, and mountain according to their morphology[9]. Around 1/3 of the thrombi in the left atrium were movable. Although CCT is of high spatial resolution, its temporal resolution is $4\sim17$ Hz, and it takes 60ms \sim 250ms to acquire one slice[8, 10-12]. Compared to TEE, which allows live display with a high spatiotemporal resolution (<1mm, 20 \sim 30Hz)[13], CCT is theoretically inferior for identifying moving objects in the left atrium. In addition, the circulatory stasis and the fibrillation of the atrial wall during AF also increase the difficulty of detecting movable thrombi[14]. In previous studies, the presence of LAA thrombus was 2(0.24%) \sim 16(19.04%)[2-5, 15]. The high sensitivity and negative predictive value of CCT could be attributed to the low incidence of movable thrombus. Therefore, it is essential to investigate

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the diagnostic accuracy of CCT in a larger cohort with a higher incidence of LAA thrombus. In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation for AF. 57(7.9%) patients were diagnosed with LAA thrombi using TEE. We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negative results.

Methods

Study population

From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital. Those who had both examinations within a 12-hour interval on the same day were retrospectively included. All the patient characteristics and images were acquired from the clinical database. The CHA₂DS₂-VASc score was calculated following the 2020 ESC guideline[1]. The study was approved by the institutional ethics committee of Guizhou Provincial People's Hospital. The informed consent was waived due to the retrospective nature, and no identified information was collected.

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CCT protocol

All patients were examined with a third-generation dual-source CT (SOMATOM Force, Siemens Healthineers, Forchheim, Germany). The imaging protocol included a standard

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angiographic-phase acquisition to assess the anatomy of the left atrium and one delayed-phase acquisition at 30 s after contrast injection to detect thrombi. No electrocardiography gating was used. The tube voltage and current were automatically adjusted using the CARE kV or CARE DOSE 4D with the reference of 100kv and 250mA. The gantry rotation time was 250ms, and the detector collimator was 192×0.6 mm. The scanning image covers the range from the aortic arch to the cardiac base. The monitoring site was localized within the left atrium. The contrast material containing 350 mg/ml of iodine was administrated intravenously at 4-5 ml/s with a total dose of 35 ml by a double-barrel syringe, followed by the same amount of 0.9% saline. For the angiographic phase, the scanning was triggered when the monitoring site reached 90 HU. Then the delayed phase was acquired 30 s later. All images were reconstructed using the ADMIRE algorithm grade 3 with a layer thickness of 1 mm and interlayer spacing of 0.7 mm. The 3D left atrium and pulmonary veins were reconstructed using the Syngo.via software (Siemens Healthcare, Forchheim, Germany).

CCT image analysis

Images were transferred to an external workstation (Syngo VPCT body, Siemens Healthcare, Forchheim, Germany). Two independent radiologists with more than eight years of cardiovascular imaging, blinded to all patients' data, retrospectively evaluated the presence of LAA thrombus and LAA morphology. Thrombus was defined as a persistent filling defect in the 30s-delayed scans. The LAA morphology was classified into simple or complex according to their main and branching structures on the 3D reconstructions[16]. In case of disagreement, a final joint reading was performed to achieve consensus.

Transesophageal echocardiology

A PhilipsiEPIQ7C color Doppler ultrasound diagnostic instrument (Philips, Amsterdam, the Netherlands) and an X7-2t probe were used. The left atrium and LAA were scanned using a complete 2D, colored, pulsed, and continuous-wave Doppler echocardiogram according to the EACVI recommendations[17]. Thrombi were defined as circumscribed echogenic or echolucent masses distinct from the atrial wall. LAA ostium was defined as within the 5mm range of the junction between the smooth atrial wall and trabeculated LAA. The dimensions and locations of thrombi were assessed if present. The LAA filling and emptying velocity was averaged by ten consecutive measurements of the backward and forward flow rates using the pulsed wave Doppler. LAA mean flow velocity (LAAMFV) was calculated by halving the sum of the LAA filling and emptying velocity. Two independent cardiologists with more than five years of experience in echocardiology evaluated the presence of LAA thrombus and measured the flow velocity. Disagreements were resolved by consensus.

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Statistical analysis

Continuous variables were expressed as mean \pm SD deviation. The Student's t-test was used for comparison if normally distributed; otherwise, the Mann-Whitney U test was used. Categorical variables were expressed as frequency (percentage). The Chi-square test was used for comparison if the expected frequency is more than 5; otherwise, Fisher's exact test was used. A two-tailed *p* value of less than 0.05 was considered statistically significant. Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was calculated. Multivariate logistic regression model was conducted to determine the predictors of CCT false-negative results. The receiver operating characteristics (ROC) curve with the area under the curve (AUC) was calculated to evaluate the performance of the predictive model. All statistical analysis was performed using SPSS 26.0.

Results

Patient characteristics

A total of 726 patients (age: 61 ± 11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Figure 1). The patients with LAA thrombus had a higher incidence of previous stroke/transient ischemic attack (TIA) and congestive heart failure, larger left atrial size, worse left ventricular function, and a higher rate of complex LAA morphology than those without LAA thrombus (p < 0.05) (Table 1).

Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. The clinical characteristics and maximum thrombus diameter were similar between the patients. The thrombi at the LAA ostium were accompanied by higher LAA filling and emptying velocities than those in the LAA (Supplementary material online, Table S1). The former also showed significantly higher mobility following the blood flow and cardiac motion than the latter (Supplementary material online, Video S1).

Diagnostic accuracy of CCT

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The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% to the LAA thrombi (Table 1). However, the CCT was less sensitive to the thrombi at LAA ostium than those in the LAA (48.3% vs. 89.3%, p = 0.001) (Supplementary material online, Table S1). Representative images are shown in Figure 2.

Given that a high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thrombi underwent further analysis. Compared with the CCT true-positive thrombi, the false-negative ones more frequently located at the LAA ostium (83.3% vs. 35.9%, p =0.001), were shorter in the maximum diameters (8 ± 2 mm vs. 14 ± 9 mm, p < 0.001), and were accompanied by higher LAA filling and emptying velocities (0.53±0.15 m/s vs. 0.38±0.19 m/s, p = 0.001; 0.55±0.21 m/s vs. 0.37±0.14 m/s, p < 0.001) (Table 2). The result was also concordant in the LAA-ostium thrombi subgroup (Supplementary material online, Table S2). By scattering the CCT results on the 2-D plane that consisted of LAAMFV and thrombus maximum diameter, the thrombi at the LAA ostium with the LAAMFVs higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results (Figure 3A). For the thrombi in the LAA, the maximum diameter or LAAMFV did not impact the CCT results (Figure 3B). In the logistic regression model, the thrombus maximum diameter, location, and LAA mean flow velocity (LAAMFV) were independently associated with the CCT false-negative results (Supplementary material online, Table S3). The ROC curve (AUC: 0.909, 95%CI: 0.834 ~ 0.984) is shown in Figure S1.

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Discussion

Major findings

We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF. TEE identified 57(7.9%) patients with LAA thrombi, of which 29(50.9%) were at the LAA ostium and 28(49.1%) in the LAA. The CCT was less sensitive in detecting LAA-ostium thrombi with smaller maximum diameters and higher

LAAMFV.

Concordance

LAA thrombus is thought to form initially inside the LAA, where circulatory stasis is the greatest, and then extends towards the ostium. However, we found over half of the thrombi located at the LAA ostium. The result was concordant with a previous study in which 46.3% of the thrombi were at the entrance section of LAA[9]. The presence of pits and troughs adjacent to the LAA orifice was reported in 57.7% of the human heart specimens[18]. It could be the anatomic basis for thrombosis. Another study using TEE discovered small recesses proximal to the entry of LAA in a significant number of patients, but no thrombus related to these structures was detected following LAA occlusion[19]. The discrepancy could be due to patient selection bias. Nonetheless, our findings raised concerns about the role of LAA-ostium recesses in thrombosis.

Although the third-generation 64-slice dual-source CT was employed in the current study, its sensitivity to LAA thrombi was not improved. The sensitivity of 89.3% to the thrombi in the LAA was comparable to the previous studies[2, 10, 11, 20-22]. However, the

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sensitivity significantly decreased for the LAA-ostium thrombi, which showed higher motility following blood flow and heartbeats than those in the LAA (Supplementary material online, Video S1). We further identified that the LAA-ostium thrombi with smaller sizes and higher LAA flow velocity were more prone to be missed using the CCT. As a higher temporal resolution is essential to detect movable objects[23], our findings suggested the impact of thrombus motility on CCT imaging. By calculating the gantry rotation time of 250ms, the CCT had a temporal resolution of 4Hz, significantly less than that of the TEE (20–40Hz). Thus, the low sensitivity of CCT in our study could be presumed to: (1) inadequate temporal resolution, (2) the high proportion of movable LAA-ostium thrombi, (3) the lack of ECG gating, (4) only one 30s delayed scan was used. The 4 CCT false-positive results in our study could be the misdiagnosis of thrombus due to circulatory stasis during AF[6, 24].

Discordance

Several studies reported that the CCT had 100% sensitivity in detecting LAA thrombi using ECG gating, single-segment reconstruction algorithm[25, 26], or multiple delayed-phase scans[3, 14, 27]. However, these studies have the following limitations: (1) Although the single-segment reconstruction algorithm increased the CCT's temporal resolution to 12Hz, the low incidence of LAA thrombus [2(0.24%) ~16(19.04%)] and the less variation of thrombus location could have overestimated the sensitivity of CCT for detecting LAA thrombi in a broader range of patients. (2) The multiple delayed-phase scans distinguished the thrombi from filling defects due to circulatory stasis. Still, the technique could not necessarily increase the sensitivity to smaller and movable thrombi at the LAA ostium.

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We suggest that the CCT approach to detect LAA thrombi could differ according to their location and motility. Persistent filling defects in multiple delayed-phase scans have been well established for static thrombi in LAA. However, LAA-ostium thrombi could be highly motile due to blood flow and myocardial contraction. In our study, the LAA flow velocity indirectly reflected the thrombus motility. The filling defects that indicate the presence of thrombi could still be enhanced as the thrombi swayed much faster than the duration required for scanning. Furthermore, the filling defect size also depended on the thrombi size. Therefore, smaller LAA-ostium thrombi with higher LAA flow velocity could be prone to be missed by CCT. A temporal resolution comparable to TEE (20~40Hz) could be necessary.

Clinical implication

Our study found that the CCT with a 30s delayed scan did not reliably exclude LAA thrombus, especially those located at the LAA ostium. We did not find any clinical characteristics associated with the thrombus location. TEE is the only recommendation for stroke risk management for patients undergoing catheter ablation of AF in the 2020 ESC guideline[1]. For those who do not tolerate TEE, intracardiac echocardiography could be considered[28].

Limitations

Firstly, this retrospective single-center study included only patients undergoing catheter ablation for AF. The study's findings may not be generalizable to other patients with AF. Secondly, the CCT protocol contained only one delayed-phase scan. Whether multiple

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delayed-phase scans reduce false-negative CCT results is unclear. Thirdly, other factors unaccounted for in this analysis - heart rhythm, atrial/ventricular rate, and blood pressure during the TEE and CCT – could affect the conclusions. Fourthly, although the interval between the TEE and CCT was less than 12 hours, it is theoretically possible for thrombi to form or disappear within this timeframe. Lastly, the incidence of LAA thrombus was higher than that in previous studies (partially due to less adherence to anticoagulation treatment), which could have affected the thrombus location and motility.

Conclusions

In patients undergoing catheter ablation of AF, CCT with a 30s delay scan is less sensitive than TEE in detecting LAA thrombi, especially those located at LAA ostium with smaller sizes and higher LAA flow velocity. 1eg

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Data sharing statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Ethical approval

 This study received approval from the institutional ethics committee of Guizhou Provincial People's Hospital.

Contributors

Chuxian Guo and Zhi Jiang: Conceptualization, Methodology, Formal analysis, Writingoriginal draft, Writing – review & editing. Jionghong He, Haiyan Ma, and Yuquan Wang: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing. Jing Tan: Conceptualization, Methodology, Investigation, Writing – review & editing. Qiaoqiao Ou: Conceptualization, Investigation, Writing – review & editing. Ye Tian and Qifang Liu: Conceptualization, Writing – review & editing, Funding acquisition. Longhai Tian and Jing Huang: Conceptualization, Investigation, Writing – review & editing. Long Yang: Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision, Funding acquisition. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Supplementary Materials

Video S1 Representative TEE video of the thrombi at LAA ostium (A-C) and those in

the LAA (D-F).

Table S1 Patient characteristics between thrombus locations.

Table S2 Patient characteristics between true-positive and false-negative CCT results.

Table S3 Multivariate analysis of the predictors for false-negative CCT results.

Figure S1 The ROC curve of the logistic regression model for predicting false-negative

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CCT results.

Abbreviation: AUC= area under the curve; CCT = cardiac computer tomography; CI =

confidence interval; ROC= receiver operating characteristics.

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Figure 1 Patient flowchart.

Abbreviations: AF = atrial fibrillation; CCT = cardiac computed tomography; LAA = left atrial appendage; TEE = transesophageal echocardiography.

Figure 2 Representative CCT and TEE images of the LAA thrombi.

The left and middle images are from the CCT angiographic and delayed phase. The right images are from the TEE. A-C. Representative false-negative CCT result of the thrombus in the LAA. D-F. Representative false-negative CCT result of the LAA-ostium thrombus. G-I. Representative true-positive CCT result of the thrombus in the LAA. J-L. Representative true-positive CCT result of the thrombus. White arrows denote the thrombi. Abbreviation: CCT = cardiac computer tomography; LAA = left atrial appendage. Enseignement Superieur (ABES) . Protected by copyright, including for uses related to text and data mining, Al training, and similar technologies.

Figure 3 Scatter plots of CCT results.

Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. For the LAA-ostium thrombi, the CCT false-negative results had the LAAMFV higher than 0.35 m/s and maximum diameters less than 10 mm. B. For the thrombi in the LAA, the maximum diameter or LAAMFV did not significantly impact CCT results. **Abbreviations:** CCT = cardiac computed tomography; LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity.

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Table 1 Patient characteristics.

	LAA thrombus *			
Characteristics	Overall (n=726)	Positive (n=57)	Negative (n=669)	<i>P</i> value
Age, year	61±11	64±10	61±11	0.129
Male	437(60.2)	36(63.2)	401(59.9)	0.634
Paroxysmal AF	436(60.1)	30(52.6)	406(60.7)	0.233
AF course, month	42±83	39±45	43±85	0.540
CHA ₂ DS ₂ -VASc score	2±2	3±2	2±2	0.089
Congestive heart failure	116(16.0)	18(31.6)	98(14.6)	0.001
Hypertension	346(47.7)	25(43.9)	321(48.0)	0.550
Diabetes mellitus	107(14.7)	10(17.5)	97(14.5)	0.534
Previous Stroke/TIA	91(12.5)	14(24.6)	77(11.5)	0.004
Vascular disease	292(40.2)	22(38.6)	270(40.4)	0.795
LAAPD, mm	36±7	41±9	36±7	< 0.001
LVEDD, mm	46±5	49±7	46±5	0.006
LVEF, %	60±8	56±11	60±7	0.005
Complex LAA morphology	289(39.8)	35(61.4)	254(38.0)	0.001
CCT results		× /	· · · · · · · · · · · · · · · · · · ·	
Filling defects	43(5.9)	39(68.4)	4(0.6)	<0.00
No filling defects	683(94.1)	18(31.6)	665(99.4)	< 0.00

Values are mean \pm SD or n (%).

* The thrombi were detected using the TEE.

Abbreviations: AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc =

congestive heart failure, hypertension, age \geq 75 years (doubled), diabetes, previous stroke/transient

ischemic attack/thromboembolism (doubled), vascular disease, age 65-74 years and sex category (female);

LAA = left atrial appendage; LAAPD = left atrial anterior-posterior diameter; LVEDD = left ventricular

end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal

echocardiography; TIA = transient ischemic attack.

	LAA thrombus *			
Characteristics	CCT false-negative result (n=18)	CCT true-positive result (n=39)	P value	
Age, years	64±9	64±10	0.810	
Male	11(61.1)	25(64.1)	0.828	
Paroxysmal AF	12(66.7)	18(46.2)	0.149	
AF course, month	42±54	38±40	0.952	
CHA ₂ DS ₂ -VASc score	3±2	3±2	0.450	
Congestive heart failure	5(27.8)	13(33.3)	0.675	
Hypertension	10(55.6)	15(38.5)	0.227	
Diabetes mellitus	5(27.8)	5(12.8)	0.168	
Previous Stroke/TIA	5(27.8)	9(23.1)	0.702	
Vascular disease	7(38.9)	15(38.5)	0.975	
LAAPD, mm	41±9	41±9	0.770	
LVEDD, mm	49±6	49±7	0.336	
LVEF, %	59±9	55±12	0.331	
Complex LAA	9(50.0)	26(66.7)	0.230	
LAA filling velocity, m/s	0.53±0.15	0.38±0.19	0.002	
LAA emptying velocity, m/s	0.55±0.21	0.37±0.14	0.001	
Thrombi maximum diameter, mm	8±2	14±9	< 0.001	
Thrombus location				
LAA ostium	15(83.3)	14(35.9)	0.001	
In LAA	3(16.7)	25(64.1)	0.001	

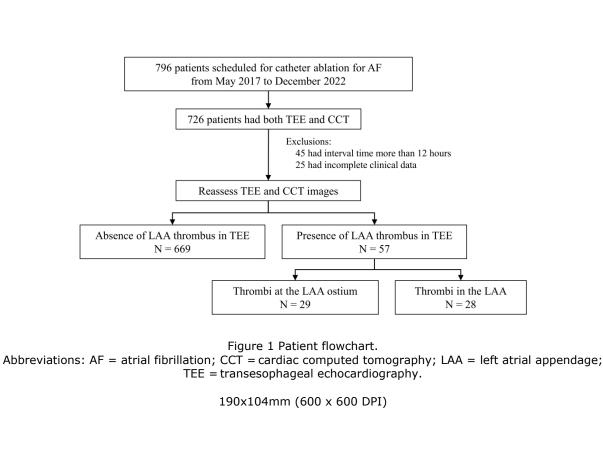
Table 2 Patient characteristics between CCT true-positive and false-negative results.

* The thrombi were detected using the TEE.

Abbreviations: AF = atrial fibrillation; $CCT = cardiac computed tomography; <math>CHA_2DS_2$ -VASc = congestive heart failure, hypertension, age ≥ 75 years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAPD = left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

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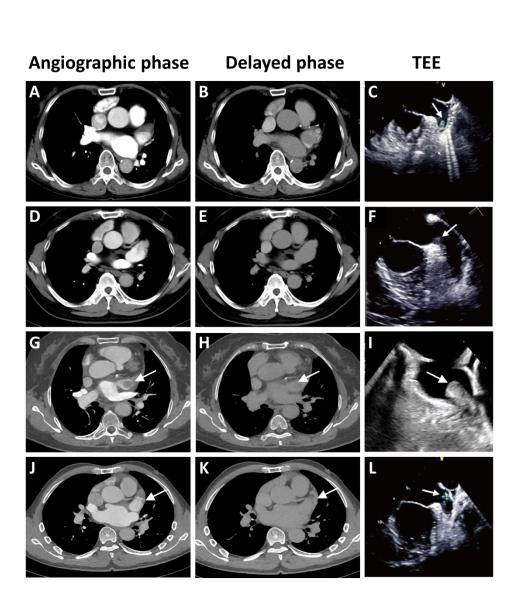


Figure 2 Representative CCT and TEE images of the LAA thrombi.

The left and middle images are from the CCT angiographic and delayed phase. The right images are from the TEE. A-C. Representative false-negative CCT result of the thrombus in the LAA. D-F. Representative false-negative CCT result of the LAA-ostium thrombus. G-I. Representative true-positive CCT result of the thrombus in the LAA. J-L. Representative true-positive CCT result of the thrombus. White arrows denote the thrombi.

Abbreviation: CCT = cardiac computer tomography; LAA = left atrial appendage.

116x128mm (600 x 600 DPI)



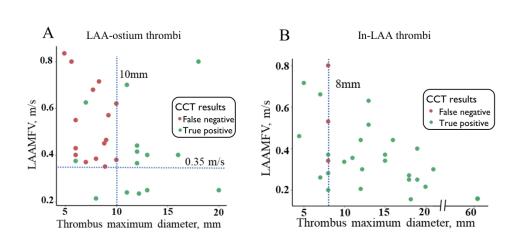


Figure 3 Scatter plots of CCT results.

Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. For the LAA-ostium thrombi, the CCT false-negative results had the LAAMFV higher than 0.35 m/s and maximum diameters less than 10 mm. B. For the thrombi in the LAA, the maximum diameter or LAAMFV did not significantly impact CCT results.

Abbreviations: CCT = cardiac computed tomography; LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity.

190x89mm (600 x 600 DPI)

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Table S1 Patient characteristics between thrombus locations.

	Thrombus locations *		- P value	
Characteristics -	LAA ostium (n=29)	In LAA (n=28)	P value	
Age, years	63±10	64±10	0.886	
Male	20(69.0)	16(57.1)	0.355	
Paroxysmal AF	18(62.1)	12(42.9)	0.146	
AF course, month	40±52	39±35	0.648	
CHA ₂ DS ₂ -VASc score	2±2	3±2	0.220	
Congestive heart failure	9(31.0)	9(32.1)	0.928	
Hypertension	10(34.5)	15(53.6)	0.147	
Diabetes mellitus	5(17.2)	5(17.9)	1.000	
Previous Stroke/TIA	7(24.1)	7(25.0)	0.940	
Vascular disease	9(31.0)	13(46.4)	0.233	
LAAPD, mm	41±10	40±8	0.873	
LVEDD, mm	49±6	49±8	0.492	
LVEF, %	57±11	55±11	0.424	
Complex LAA	17(58.6)	18(64.3)	0.661	
LAA filling velocity, m/s	0.48 ± 0.19	0.37±0.19	0.021	
LAA emptying velocity, m/s	0.47 ± 0.20	0.38±0.16	0.050	
LAAMFV, m/s	0.47 ± 0.18	0.37±0.17	0.029	
Thrombus maximum diameter, mm	10±4	14±10	0.045	
CCT results				
Filling defects	14(48.3)	25(89.3)	0.001	
No filling defects	15(51.7)	3(10.7)	0.001	

Values are mean \pm SD or n (%).

* The thrombus locations were determined using the TEE.

The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. **Abbreviations:** $AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc = congestive heart failure, hypertension, age <math>\geq 75$ years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity; LAAPD= left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

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	LAA-ostiu	m thrombi [*]	
Characteristics	CCT false-negative result	CCT true-positive result	P value
	(n=15)	(n=14)	
Age, years	63±10	64±10	0.726
Male	10(66.7)	10(71.4)	1.000
Paroxysmal AF	10(66.7)	8(57.1)	0.597
AF course, month	44±58	36±45	0.677
CHA ₂ DS ₂ -VASc score	3±2	2±2	0.288
Congestive heart failure	4(26.7)	5(35.7)	0.700
Hypertension	8(53.3)	2(14.3)	0.050
Diabetes mellitus	4(26.7)	1(7.1)	0.330
Previous Stroke/TIA	4(26.7)	3(21.4)	1.000
Vascular disease	6(40.0)	3(21.4)	0.427
LAAPD, mm	39±9	44±11	0.221
LVEDD, mm	49±6	48±5	0.370
LVEF, %	59±8	55±13	0.444
Complex LAA	7(46.7)	10(71.4)	0.264
LAA filling velocity, m/s	0.52±0.15	0.43±0.21	0.110
LAA emptying velocity, m/s	0.55±0.21	0.38±0.15	0.027
LAAMFV, m/s	0.53±0.16	0.41±0.18	0.047
Thrombus maximum diameter, mm	8±2	12±4	0.001

Table S2 Patient characteristics between true-positive and false-negative CCT results.

Values are mean \pm SD or n (%).

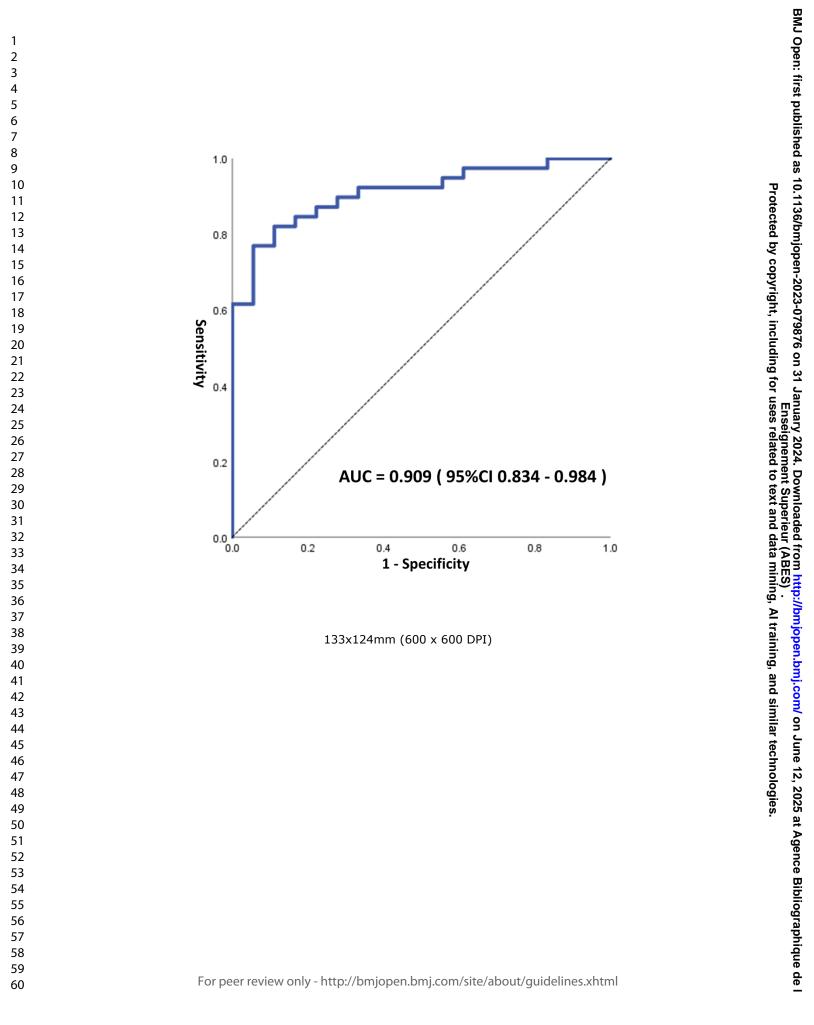
* The LAA-ostium thrombi were determined using the TEE.

The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity.

Abbreviations: $AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc = congestive heart failure, hypertension, age <math>\geq 75$ years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity; LAAPD= left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

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AA-ostium thrombus $10.981 (1.702 \sim 70.831) 0.0$	0.000 0.012 0.117	0.635 (0.459 ~ 0.879)	
AAMFV, per 1 m/s increase 47.926 (0.382 ~ 6014.699) 0.			Thrombus maximum diameter, per 1 mm decrease
bbreviations: CCT = cardiac computer tomography; CI = confidence interval; LAA = ppendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.	0.117	10.981 (1.702 ~ 70.831)	LAA-ostium thrombus
ppendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.	0.11	47.926 (0.382 ~ 6014.699)	LAAMFV, per 1 m/s increase
ppendage; LAAMFV = left atrial appendage mean flow velocity; OR = odd ratio.	A = let	hy; CI = confidence interval; LA.	Abbreviations: CCT = cardiac computer tomograph
		flow velocity; OR = odd ratio.	ppendage; LAAMFV = left atrial appendage mean



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STROBE Stateme	nt—ch	ecklist of items that should be included in reports of observational studies	inclu	79876	
	Item No.	Recommendation	ding fo	Page Δ No.	Relevant text from manuscript
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	BES) . mining, Al training,	y 2024. Downloaded from http://bmjopen.b	 From May 2017 to December 2022, 726 patients (male: 60.2%, age: 61±11 years) who had both TEE and CCT before catheter ablation of AF were retrospectively included. Our study aims to evaluate the accuracy of CCT for detecting LAA thrombus in patients undergoing catheter ablation of atrial fibrillation (AF), using transesophageal echocardiography (TEE) as the reference standard.
Introduction Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5 ⁵ similar technologies.	mj.com/ on June 12, 2025 at Age	Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)
Objectives	3	State specific objectives, including any prespecified hypotheses	5	ence Bibliographique	We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negative
		For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtr		hique de l	

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		99 	njopen-2023-079876	results.
Methods			6 9	
Study design	4		njopen-2023-079876 on 31 January 2024. E Enseigneme	All the patient characteristics and images were acquired from the clinical database. The CHA2DS2-VASc score was calculated following the 2020 ESC guideline.
Setting	5		Downloaded from http://bmjoper nt Superieur (ABES)	From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital. Those who had both examinations within a 12-hour interval on the same day were retrospectively included.
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Give the eligibility criteria, and the sources and methods of selection of participants <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants Give the eligibility criteria, and the sources and methods of selection of participants (b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case	.bmj.com/ on June 12, 2025 at Age	In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation for AF.
Variables	7		6,7 e Bibliographique de	Thrombus was defined as a persistent filling defect in the 30s-delayed scans. The LAA morphology was classified into

BMJ Open by copyright, including for USes related to text a 8* For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	simple or complex according to their main and branching structures on the 3D reconstructions All patients were examined with a third-generation dual-source CT. The imaging protocol included a standard angiographic-phase acquisition
8* For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	a third-generation dual-source CT. The imaging protocol included a standard
aded from arieur (AE	to assess the anatomy of the lef atrium and one delayed-phase acquisition at 30 s after contras injection to detect thrombi
9 Describe any efforts to address potential sources of bias 9 Describe any efforts to address potential sources of bias 9 At training, and similar techn 1 The second on June 1	Two independent radiologists with more than eight years of cardiovascular imaging, blinde to all patients' data Two independent cardiologists with more than five years of experience in echocardiology evaluated the presence of LAA thrombus and measured the flow velocity
10 Explain how the study size was arrived at	In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation for AF.
e Bibliographique G For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml	
	10 Explain how the study size was arrived at

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Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	ıjopen-2023-079876 on 31 . by copyright, ^m cluding fo	Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was calculated.
Statistical methods	12	(<i>a</i>) Describe all statistical methods, including those used to control for confounding	January 2024, Downloaded from http Enseignement Superieur (ABES) r uses related to text and data minn	Continuous variables were expressed as mean ± SD deviation
		(b) Describe any methods used to examine subgroups and interactions		
		(c) Explain how missing data were addressed		
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed		Using TEE as the reference
		Case-control study—If applicable, explain how matching of cases and controls was addressed	ade	standard, the diagnostic
		Cross-sectional study—If applicable, describe analytical methods taking account of sampling	d fr Jar (/ data	performance of CCT for LAA
		strategy		thrombi was calculated.
		(<u>e</u>) Describe any sensitivity analyses		
Results			g, A	
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	njopen.bmj.com/ on training, and similar	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram	June 12, 2025 at téchnologies.	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Agence Bibliographique de	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1)
		4 For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xht	ique de I	

37 of 37	BMJ Open	njopen-202 by copyri	
	(b) Indicate number of participants with missing data for each variable of interest	njopen-2023-079876 on 31 Janu Ei 4 by copyright, ^a ncluding for us	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Fig. 1).
	(c) Cohort study—Summarise follow-up time (eg, average and total amount)	nsei es m	
Outcome data	* <u>Cohort study</u> —Report numbers of outcome events or summary measures over time		
	Case-control study—Report numbers in each exposure category, or summary measures of o	y 2024. Downloaded from http://bmjopen.bmj.com/ on June 12, 2025 ; pighement Superieur (ABES) . refated to text and data mining, AI traffing; and similar technologies. recision hey were	Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. Compared with the CCT true- positive thrombi, the false-negativ ones more frequently located at the LAA ostium (83.3% vs. 35.9%, p 0.001)
	Cross-sectional study—Report numbers of outcome events or summary measures		
Main results	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their p (eg, 95% confidence interval). Make clear which confounders were adjusted for and why the included	hey were and sir	
	(b) Report category boundaries when continuous variables were categorized	at Age	Given that high sensitivity is essential to exclude LAA thrombut the CCT results of the LAA thrombi underwent further analysi By scattering the CCT results on the 2-D plane, the thrombi at the LAA ostium
	(c) If relevant, consider translating estimates of relative risk into absolute risk for a meanin period	gful time N/A	
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17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% Given that high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thrombi underwent further analysis
18	Summarise key results with reference to study objectives	ownloaded fro t Superieur (<i>I</i> Text and data	We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF.
19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	om http://bmjo A&ES) . 1 mining, Al tra	Firstly, this retrospective single- center study included only patients undergoing catheter ablation for AF
20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	pgn.bmj.co 0, aintng, and	Thus, the low sensitivity of CCT in our study could be presumed to: (1) inadequate temporal resolution
21	Discuss the generalisability (external validity) of the study results		This retrospective single-center study included only patients undergoing catheter ablation for AF. The study's findings may not be generalizable to other patients with AF
on		7	
22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13 gence Bibliographique de	This study has received funding from the Science and Technology Support plan of Guizhou Province
	18 19 20 21 on	 17 Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses 18 Summarise key results with reference to study objectives 18 Summarise key results with reference to study objectives 19 Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias 20 Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence 21 Discuss the generalisability (external validity) of the study results on 22 Give the source of funding and the role of the funders for the present study and, if applicable, for the 	17 Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses International sensitivity analyses 17 Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses International sensitivity analyses 18 Summarise key results with reference to study objectives International sensitivity analyses 19 Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias International sensitivity of analyses, results from similar studies, and other relevant evidence 20 Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence International sector sec

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 *Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in solo
 and cross-sectional studies.

 Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE

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Impact of left atrial appendage thrombus location on diagnostic accuracy of cardiac computer tomography: a single-center case-control study

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Primary Subject Heading :	Cardiovascular medicine			
Secondary Subject Heading:	Cardiovascular medicine, Radiology and imaging			
Keywords:	Stroke < NEUROLOGY, Ultrasound < RADIOLOGY & IMAGING, Computed tomography < RADIOLOGY & IMAGING, Thromboembolism < CARDIOLOGY			
Note: The following files were s You must view these files (e.g.	ubmitted by the author for peer review, but cannot be converted to PDF. movies) online.			
Supplementary material_Video S1.mp4				

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Running Head: Detection of Left Atrial Appendage Thrombus Using Cardiac CT

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* Chuxian Guo and Zhi Jiang contributed equally to the study.

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Objective Cardiac computed tomography (CCT) is an emerging non-invasive modality for assessing left atrial appendage (LAA) thrombus, but the results were conflicting. Our study aims to evaluate the accuracy of CCT for detecting LAA thrombus in patients undergoing catheter ablation of atrial fibrillation, using transesophageal echocardiography (TEE) as the reference standard.

Design Case-control study.

Setting Patient data were collected from a tertiary hospital in China between 2017 and 2022.Participants The study enrolled 726 patients (male: 60.2%, age: 61±11 years) who had both TEE and CCT before catheter ablation of atrial fibrillation.

Measures The CCT protocol consisted of one angiographic phase and one delayed scan 30 seconds later. LAA thrombi were defined as solid masses on TEE or persistent defects on CCT. The thrombus dimension and location, the LAA filling and emptying flow velocity were assessed by TEE.

Results Of the 57(7.9%) patients with LAA thrombi identified by TEE, 29(50.9%) were located at the LAA ostium, and 28(49.1%) were in the LAA. The former showed higher motility following blood flow and heartbeats than the latter. The CCT detected 14(48.3%) of the LAA-ostium thrombi but 25(89.3%) of those in the LAA (p = 0.001). The LAA-ostium thrombi with the LAA mean flow velocity higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results.

Conclusion For patients undergoing catheter ablation for atrial fibrillation, CCT with a 30s delay scan is less sensitive to LAA thrombi than TEE, especially for LAA-ostium thrombi with smaller sizes and higher LAA flow velocity.

Keywords stroke; embolism; thrombosis; pulmonary vein isolation; cardiac imaging techniques; ultrasound.

Strengths and limitations of this study

1. A major strength of our study is based on a large cohort with high incidence of left atrial appendage thrombi.

2. We first report the impact of thrombus location on the sensitivity of CCT, using TEE as

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reference standard.

3. A limitation of this study is that it is a single-center and retrospective study.

4. The CCT protocol contained only one delayed-phase scan. Whether multiple delayed-phase

scans reduce false-negative CCT results is unclear.

Title: Impact of left atrial appendage thrombus location on diagnostic accuracy of cardiac computer tomography: a single-center case-control study

Introduction

 Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)[1]. In the past decades, cardiac computed tomography (CCT) has been widely studied for detecting LAA thrombus[2-5]. Recently, the delayed contrast-enhanced CCT at 6 minutes was reported to reach 100% sensitivity and negative predictive value in detecting LAA thrombus[6]. For patients who are not tolerant of the discomfort associated with TEE, CCT is proposed as a reliable alternative[7]. However, the accuracy of CCT varied between studies[2-5, 8], raising the safety concern and limiting the routine use of CCT.

The left atrial thrombi were classified into a movable ball, fixed ball, and mountain according to their morphology[9]. Around 1/3 of the thrombi in the left atrium were movable. Although CCT is of high spatial resolution, its temporal resolution is 4~17Hz, and it takes 60ms ~ 250ms to acquire one slice[8, 10-12]. Compared to TEE, which allows live display with a high spatiotemporal resolution (<1mm, 20~30Hz)[13], CCT is theoretically inferior for identifying moving objects in the left atrium. In addition, the circulatory stasis and the fibrillation of the atrial wall during AF also increase the difficulty of detecting movable thrombi[14]. In previous studies, the presence of LAA thrombus was 2(0.24%) ~16(19.04%)[2-5, 15]. The high sensitivity and negative predictive value of CCT could be attributed to the low incidence of movable thrombus. Therefore, it is essential to investigate

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the diagnostic accuracy of CCT in a larger cohort with a higher incidence of LAA thrombus. In the current study, we retrospectively included 726 patients who had both TEE and CCT before catheter ablation for AF. 57(7.9%) patients were diagnosed with LAA thrombi using TEE. We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negative results.

Methods

Study population

From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital. Those who had both examinations within a 12-hour interval on the same day were retrospectively included. All the patient characteristics and images were acquired from the clinical database. The CHA₂DS₂-VASc score was calculated following the 2020 ESC guideline[1]. The study was approved by the institutional ethics committee of Guizhou Provincial People's Hospital. The informed consent was waived due to the retrospective nature, and no identified information was collected.

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CCT protocol

All patients were examined with a third-generation dual-source CT (SOMATOM Force, Siemens Healthineers, Forchheim, Germany). The imaging protocol included a standard

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angiographic-phase acquisition to assess the anatomy of the left atrium and one delayed-phase acquisition at 30 s after contrast injection to detect thrombi. No electrocardiography gating was used. The tube voltage and current were automatically adjusted using the CARE kV or CARE DOSE 4D with the reference of 100kv and 250mA. The gantry rotation time was 250ms, and the detector collimator was 192×0.6 mm. The scanning image covers the range from the aortic arch to the cardiac base. The monitoring site was localized within the left atrium. The contrast material containing 350 mg/ml of iodine was administrated intravenously at 4-5 ml/s with a total dose of 35 ml by a double-barrel syringe, followed by the same amount of 0.9% saline. For the angiographic phase, the scanning was triggered when the monitoring site reached 90 HU. Then the delayed phase was acquired 30 s later. All images were reconstructed using the ADMIRE algorithm grade 3 with a layer thickness of 1 mm and interlayer spacing of 0.7 mm. The 3D left atrium and pulmonary veins were reconstructed using the Syngo.via software (Siemens Healthcare, Forchheim, Germany).

CCT image analysis

Images were transferred to an external workstation (Syngo VPCT body, Siemens Healthcare, Forchheim, Germany). Two independent radiologists with more than eight years of cardiovascular imaging, blinded to all patients' data, retrospectively evaluated the presence of LAA thrombus and LAA morphology. Thrombus was defined as a persistent filling defect in the 30s-delayed scans. The LAA morphology was classified into simple or complex according to their main and branching structures on the 3D reconstructions[16]. In case of disagreement, a final joint reading was performed to achieve consensus.

Transesophageal echocardiology

A PhilipsiEPIQ7C color Doppler ultrasound diagnostic instrument (Philips, Amsterdam, the Netherlands) and an X7-2t probe were used. The left atrium and LAA were scanned using a complete 2D, colored, pulsed, and continuous-wave Doppler echocardiogram according to the EACVI recommendations[17]. Thrombi were defined as circumscribed echogenic or echolucent masses distinct from the atrial wall. LAA ostium was defined as within the 5mm range of the junction between the smooth atrial wall and trabeculated LAA. The dimensions and locations of thrombi were assessed if present. The LAA filling and emptying velocity was averaged by ten consecutive measurements of the backward and forward flow rates using the pulsed wave Doppler. LAA mean flow velocity (LAAMFV) was calculated by halving the sum of the LAA filling and emptying velocity. Two independent cardiologists with more than five years of experience in echocardiology evaluated the presence of LAA thrombus and measured the flow velocity. Disagreements were resolved by consensus.

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Statistical analysis

Continuous variables were expressed as mean \pm SD deviation. The Student's t-test was used for comparison if normally distributed; otherwise, the Mann-Whitney U test was used. Categorical variables were expressed as frequency (percentage). The Chi-square test was used for comparison if the expected frequency is more than 5; otherwise, Fisher's exact test was used. A two-tailed *p* value of less than 0.05 was considered statistically significant. Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was

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calculated. Multivariate logistic regression model was conducted to determine the predictors of CCT false-negative results. The receiver operating characteristics (ROC) curve with the area under the curve (AUC) was calculated to evaluate the performance of the predictive model. All statistical analysis was performed using SPSS 26.0.

Results

Patient characteristics

A total of 726 patients (age: 61 ± 11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study (Figure 1). The patients with LAA thrombus had a higher incidence of previous stroke/transient ischemic attack (TIA) and congestive heart failure, larger left atrial size, worse left ventricular function, and a higher rate of complex LAA morphology than those without LAA thrombus (p < 0.05) (Table 1).

Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. The clinical characteristics and maximum thrombus diameter were similar between the patients. The thrombi at the LAA ostium were accompanied by higher LAA filling and emptying velocities than those in the LAA (Supplementary material online, Table S1). The former also showed significantly higher mobility following the blood flow and cardiac motion than the latter (Supplementary material online, Video S1).

Diagnostic accuracy of CCT

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The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% to the LAA thrombi (Table 1). However, the CCT was less sensitive to the thrombi at LAA ostium than those in the LAA (48.3% vs. 89.3%, p = 0.001) (Supplementary material online, Table S1). Representative images are shown in Figure 2.

Given that a high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thrombi underwent further analysis. Compared with the CCT true-positive thrombi, the false-negative ones more frequently located at the LAA ostium (83.3% vs. 35.9%, p =0.001), were shorter in the maximum diameters (8 ± 2 mm vs. 14 ± 9 mm, p < 0.001), and were accompanied by higher LAA filling and emptying velocities (0.53±0.15 m/s vs. 0.38±0.19 m/s, p = 0.001; 0.55±0.21 m/s vs. 0.37±0.14 m/s, p < 0.001) (Table 2). The result was also concordant in the LAA-ostium thrombi subgroup (Supplementary material online, Table S2). By scattering the CCT results on the 2-D plane that consisted of LAAMFV and thrombus maximum diameter, the thrombi at the LAA ostium with the LAAMFVs higher than 0.35m/s and maximum diameters shorter than 10mm were more prone to have CCT false-negative results (Figure 3A). For the thrombi in the LAA, the maximum diameter or LAAMFV did not impact the CCT results (Figure 3B). In the logistic regression model, the thrombus maximum diameter, location, and LAA mean flow velocity (LAAMFV) were independently associated with the CCT false-negative results (Supplementary material online, Table S3). The ROC curve (AUC: 0.909, 95%CI: 0.834 ~ 0.984) is shown in Figure S1.

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Discussion

Major findings

We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF. TEE identified 57(7.9%) patients with LAA thrombi, of which 29(50.9%) were at the LAA ostium and 28(49.1%) in the LAA. The CCT was less sensitive in detecting LAA-ostium thrombi with smaller maximum diameters and higher

LAAMFV.

Concordance

LAA thrombus is thought to form initially inside the LAA, where circulatory stasis is the greatest, and then extends towards the ostium. However, we found over half of the thrombi located at the LAA ostium. The result was concordant with a previous study in which 46.3% of the thrombi were at the entrance section of LAA[9]. The presence of pits and troughs adjacent to the LAA orifice was reported in 57.7% of the human heart specimens[18]. It could be the anatomic basis for thrombosis. Another study using TEE discovered small recesses proximal to the entry of LAA in a significant number of patients, but no thrombus related to these structures was detected following LAA occlusion[19]. The discrepancy could be due to patient selection bias. Nonetheless, our findings raised concerns about the role of LAA-ostium recesses in thrombosis.

Although the third-generation 64-slice dual-source CT was employed in the current study, its sensitivity to LAA thrombi was not improved. The sensitivity of 89.3% to the thrombi in the LAA was comparable to the previous studies[2, 10, 11, 20-22]. However, the

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sensitivity significantly decreased for the LAA-ostium thrombi, which showed higher motility following blood flow and heartbeats than those in the LAA (Supplementary material online, Video S1). We further identified that the LAA-ostium thrombi with smaller sizes and higher LAA flow velocity were more prone to be missed using the CCT. As a higher temporal resolution is essential to detect movable objects[23], our findings suggested the impact of thrombus motility on CCT imaging. By calculating the gantry rotation time of 250ms, the CCT had a temporal resolution of 4Hz, significantly less than that of the TEE (20~40Hz). Thus, the low sensitivity of CCT in our study could be presumed to: (1) inadequate temporal resolution, (2) the high proportion of movable LAA-ostium thrombi, (3) the lack of ECG gating, (4) only one 30s delayed scan was used. The 4 CCT false-positive results in our study could be the misdiagnosis of thrombus due to circulatory stasis during AF[6, 24].

Discordance

Several studies reported that the CCT had 100% sensitivity in detecting LAA thrombi using ECG gating, single-segment reconstruction algorithm[25, 26], or multiple delayed-phase scans[3, 14, 27]. However, these studies have the following limitations: (1) Although the single-segment reconstruction algorithm increased the CCT's temporal resolution to 12Hz, the low incidence of LAA thrombus [2(0.24%) ~16(19.04%)] and the less variation of thrombus location could have overestimated the sensitivity of CCT for detecting LAA thrombi in a broader range of patients. (2) The multiple delayed-phase scans distinguished the thrombi from filling defects due to circulatory stasis. Still, the technique could not necessarily increase the sensitivity to smaller and movable thrombi at the LAA ostium.

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We suggest that the CCT approach to detect LAA thrombi could differ according to their location and motility. Persistent filling defects in multiple delayed-phase scans have been well established for static thrombi in LAA. However, LAA-ostium thrombi could be highly motile due to blood flow and myocardial contraction. In our study, the LAA flow velocity indirectly reflected the thrombus motility. The filling defects that indicate the presence of thrombi could still be enhanced as the thrombi swayed much faster than the duration required for scanning. Furthermore, the filling defect size also depended on the thrombi size. Therefore, smaller LAA-ostium thrombi with higher LAA flow velocity could be prone to be missed by CCT. A temporal resolution comparable to TEE (20~40Hz) could be necessary.

Clinical implication

Our study found that the CCT with a 30s delayed scan did not reliably exclude LAA thrombus, especially those located at the LAA ostium. We did not find any clinical characteristics associated with the thrombus location. TEE is the only recommendation for stroke risk management for patients undergoing catheter ablation of AF in the 2020 ESC guideline[1]. For those who do not tolerate TEE, intracardiac echocardiography could be considered[28].

Limitations

Firstly, this retrospective single-center study included only patients undergoing catheter ablation for AF. The study's findings may not be generalizable to other patients with AF. Secondly, the CCT protocol contained only one delayed-phase scan. Whether multiple

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 delayed-phase scans reduce false-negative CCT results is unclear. Thirdly, other factors unaccounted for in this analysis - heart rhythm, atrial/ventricular rate, and blood pressure during the TEE and CCT – could affect the conclusions. Fourthly, although the interval between the TEE and CCT was less than 12 hours, it is theoretically possible for thrombi to form or disappear within this timeframe. Lastly, the incidence of LAA thrombus was higher than that in previous studies (partially due to less adherence to anticoagulation treatment), which could have affected the thrombus location and motility.

Conclusions

In patients undergoing catheter ablation of AF, CCT with a 30s delay scan is less sensitive than TEE in detecting LAA thrombi, especially those located at LAA ostium with smaller sizes and higher LAA flow velocity. iez oni

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Data sharing statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Contributors

Chuxian Guo and Zhi Jiang: Conceptualization, Methodology, Formal analysis, Writingoriginal draft, Writing – review & editing. Jionghong He, Haiyan Ma, and Yuquan Wang: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing. Jing Tan: Conceptualization, Methodology, Investigation, Writing – review & editing. Qiaoqiao Ou: Conceptualization, Investigation, Writing – review & editing. Ye Tian and Qifang Liu: Conceptualization, Writing – review & editing, Funding acquisition. Longhai Tian and Jing Huang: Conceptualization, Investigation, Writing – review & editing. Long Yang: Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision, Funding acquisition. All authors read and approved the final manuscript.

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Ethical approval

This study received approval from the institutional ethics committee of Guizhou Provincial People's Hospital.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Supplementary Materials

Video S1 Representative TEE video of the thrombi at LAA ostium (A-C) and those in

the LAA (D-F).

Table S1 Patient characteristics between thrombus locations.

Table S2 Patient characteristics between true-positive and false-negative CCT results.

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Table S3 Multivariate analysis of the predictors for false-negative CCT results.

Figure S1 The ROC curve of the logistic regression model for predicting false-negative

CCT results.

Abbreviation: AUC= area under the curve; CCT = cardiac computer tomography; CI =

confidence interval; ROC= receiver operating characteristics.

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Figure 1 Patient flowchart.

Abbreviations: AF = atrial fibrillation; CCT = cardiac computed tomography; LAA = left atrial appendage; TEE = transesophageal echocardiography.

Figure 2 Representative CCT and TEE images of the LAA thrombi.

The left and middle images are from the CCT angiographic and delayed phase. The right images are from the TEE. A-C. Representative false-negative CCT result of the thrombus in the LAA. D-F. Representative false-negative CCT result of the LAA-ostium thrombus. G-I. Representative true-positive CCT result of the thrombus in the LAA. J-L. Representative true-positive CCT result of the thrombus. White arrows denote the thrombi. Abbreviation: CCT = cardiac computer tomography; LAA = left atrial appendage. Enseignement Superieur (ABES) . Protected by copyright, including for uses related to text and data mining, Al training, and similar technologies.

Figure 3 Scatter plots of CCT results.

Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. For the LAA-ostium thrombi, the CCT false-negative results had the LAAMFV higher than 0.35 m/s and maximum diameters less than 10 mm. B. For the thrombi in the LAA, the maximum diameter or LAAMFV did not significantly impact CCT results. **Abbreviations:** CCT = cardiac computed tomography; LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity.

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Table 1 Patient characteristics.

Characteristics	LAA thrombus *			
	Overall (n=726)	Positive (n=57)	Negative (n=669)	<i>P</i> value
Age, year	61±11	64±10	61±11	0.129
Male	437(60.2)	36(63.2)	401(59.9)	0.634
Paroxysmal AF	436(60.1)	30(52.6)	406(60.7)	0.233
AF course, month	42±83	39±45	43±85	0.540
CHA ₂ DS ₂ -VASc score	2±2	3±2	2±2	0.089
Congestive heart failure	116(16.0)	18(31.6)	98(14.6)	0.001
Hypertension	346(47.7)	25(43.9)	321(48.0)	0.550
Diabetes mellitus	107(14.7)	10(17.5)	97(14.5)	0.534
Previous Stroke/TIA	91(12.5)	14(24.6)	77(11.5)	0.004
Vascular disease	292(40.2)	22(38.6)	270(40.4)	0.795
LAAPD, mm	36±7	41±9	36±7	< 0.001
LVEDD, mm	46±5	49±7	46±5	0.006
LVEF, %	60±8	56±11	60 ± 7	0.005
Complex LAA morphology 🧹	289(39.8)	35(61.4)	254(38.0)	0.001
CCT results			```	
Filling defects	43(5.9)	39(68.4)	4(0.6)	< 0.001
No filling defects	683(94.1)	18(31.6)	665(99.4)	< 0.001

Values are mean \pm SD or n (%).

* The thrombi were detected using the TEE.

Abbreviations: AF = atrial fibrillation; $CCT = cardiac computed tomography; <math>CHA_2DS_2$ -VASc = congestive heart failure, hypertension, age ≥ 75 years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAPD = left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

	LAA thrombus *			
Characteristics	CCT false-negative result (n=18)	CCT true-positive result (n=39)	P value	
Age, years	64±9	64±10	0.810	
Male	11(61.1)	25(64.1)	0.828	
Paroxysmal AF	12(66.7)	18(46.2)	0.149	
AF course, month	42±54	38±40	0.952	
CHA ₂ DS ₂ -VASc score	3±2	3±2	0.450	
Congestive heart failure	5(27.8)	13(33.3)	0.675	
Hypertension	10(55.6)	15(38.5)	0.227	
Diabetes mellitus	5(27.8)	5(12.8)	0.168	
Previous Stroke/TIA	5(27.8)	9(23.1)	0.702	
Vascular disease	7(38.9)	15(38.5)	0.975	
LAAPD, mm	41±9	41±9	0.770	
LVEDD, mm	49±6	49±7	0.336	
LVEF, %	59±9	55±12	0.331	
Complex LAA	9(50.0)	26(66.7)	0.230	
LAA filling velocity, m/s	0.53±0.15	0.38±0.19	0.002	
LAA emptying velocity, m/s	0.55±0.21	0.37±0.14	0.001	
Thrombi maximum diameter, mm	8±2	14±9	< 0.001	
Thrombus location				
LAA ostium	15(83.3)	14(35.9)	0.001	
In LAA	3(16.7)	25(64.1)		

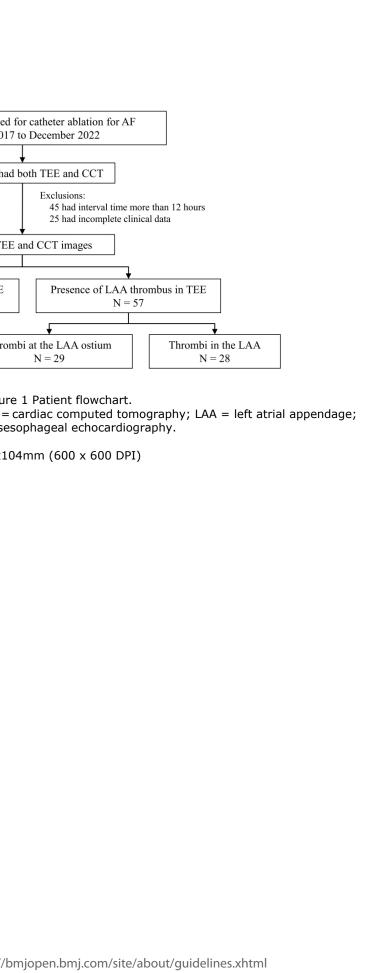
Table 2 Patient characteristics between CCT true-positive and false-negative results.

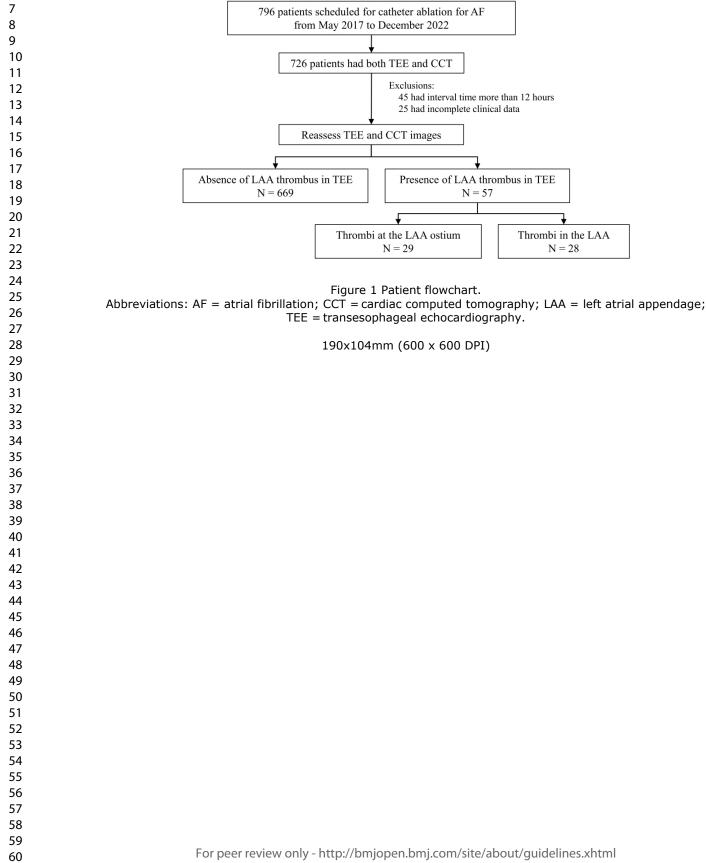
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* The thrombi were detected using the TEE.

Abbreviations: $AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc = congestive heart failure, hypertension, age <math>\geq$ 75 years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAPD = left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

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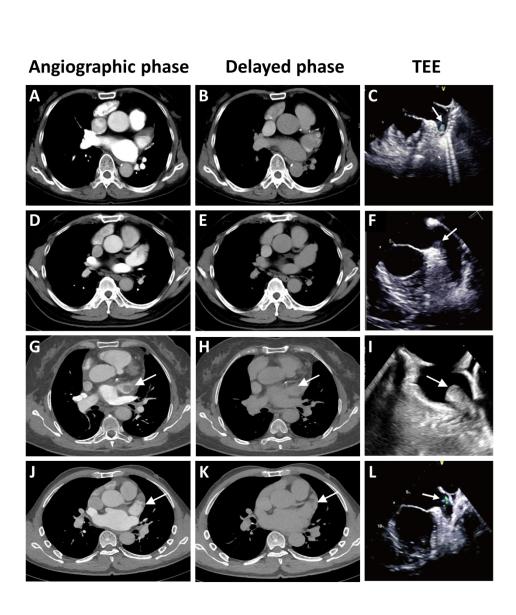


Figure 2 Representative CCT and TEE images of the LAA thrombi.

The left and middle images are from the CCT angiographic and delayed phase. The right images are from the TEE. A-C. Representative false-negative CCT result of the thrombus in the LAA. D-F. Representative false-negative CCT result of the LAA-ostium thrombus. G-I. Representative true-positive CCT result of the thrombus in the LAA. J-L. Representative true-positive CCT result of the LAA-ostium thrombus. White arrows denote the thrombi.

Abbreviation: CCT = cardiac computer tomography; LAA = left atrial appendage.

116x128mm (600 x 600 DPI)



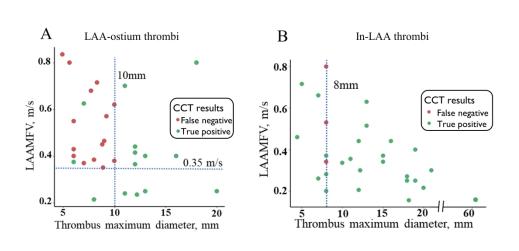


Figure 3 Scatter plots of CCT results.

Red dots denote the CCT false-negative thrombi. Green dots denote the CCT true-positive thrombi. The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. A. For the LAA-ostium thrombi, the CCT false-negative results had the LAAMFV higher than 0.35 m/s and maximum diameters less than 10 mm. B. For the thrombi in the LAA, the maximum diameter or LAAMFV did not significantly impact CCT results.

Abbreviations: CCT = cardiac computed tomography; LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity.

190x89mm (600 x 600 DPI)

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Table S1 Patient characteristics between thrombus locations.

	Thrombus lo	<i>P</i> value		
Characteristics -	LAA ostium (n=29)	In LAA (n=28)	- <i>r</i> value	
Age, years	63±10	64±10	0.886	
Male	20(69.0)	16(57.1)	0.355	
Paroxysmal AF	18(62.1)	12(42.9)	0.146	
AF course, month	40±52	39±35	0.648	
CHA ₂ DS ₂ -VASc score	2±2	3±2	0.220	
Congestive heart failure	9(31.0)	9(32.1)	0.928	
Hypertension	10(34.5)	15(53.6)	0.147	
Diabetes mellitus	5(17.2)	5(17.9)	1.000	
Previous Stroke/TIA	7(24.1)	7(25.0)	0.940	
Vascular disease	9(31.0)	13(46.4)	0.233	
LAAPD, mm	41±10	40±8	0.873	
LVEDD, mm	49±6	49±8	0.492	
LVEF, %	57±11	55±11	0.424	
Complex LAA	17(58.6)	18(64.3)	0.661	
LAA filling velocity, m/s	0.48 ± 0.19	0.37±0.19	0.021	
LAA emptying velocity, m/s	0.47 ± 0.20	0.38±0.16	0.050	
LAAMFV, m/s	0.47 ± 0.18	0.37±0.17	0.029	
Thrombus maximum diameter, mm	10±4	14±10	0.045	
CCT results				
Filling defects	14(48.3)	25(89.3)	0.001	
No filling defects	15(51.7)	3(10.7)	0.001	

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Values are mean \pm SD or n (%).

* The thrombus locations were determined using the TEE.

The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity. **Abbreviations:** $AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc = congestive heart failure, hypertension, age <math>\geq 75$ years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity; LAAPD= left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

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	LAA-ostium thrombi*				
Characteristics	CCT false-negative result (n=15)	CCT true-positive result (n=14)	<i>P</i> value		
Age, years	63±10	64±10	0.726		
Male	10(66.7)	10(71.4)	1.000		
Paroxysmal AF	10(66.7)	8(57.1)	0.597		
AF course, month	44±58	36±45	0.677		
CHA ₂ DS ₂ -VASc score	3±2	2±2	0.288		
Congestive heart failure	4(26.7)	5(35.7)	0.700		
Hypertension	8(53.3)	2(14.3)	0.050		
Diabetes mellitus	4(26.7)	1(7.1)	0.330		
Previous Stroke/TIA	4(26.7)	3(21.4)	1.000		
Vascular disease	6(40.0)	3(21.4)	0.427		
LAAPD, mm	39±9	44±11	0.221		
LVEDD, mm	49±6	48±5	0.370		
LVEF, %	59±8	55±13	0.444		
Complex LAA	7(46.7)	10(71.4)	0.264		
LAA filling velocity, m/s	0.52±0.15	0.43±0.21	0.110		
LAA emptying velocity, m/s	0.55±0.21	0.38±0.15	0.027		
LAAMFV, m/s	0.53±0.16	0.41 ± 0.18	0.047		
Thrombus maximum diameter, mm	u 8±2	12±4	0.001		

Table S2 Patient characteristics between true-positive and false-negative CCT results.

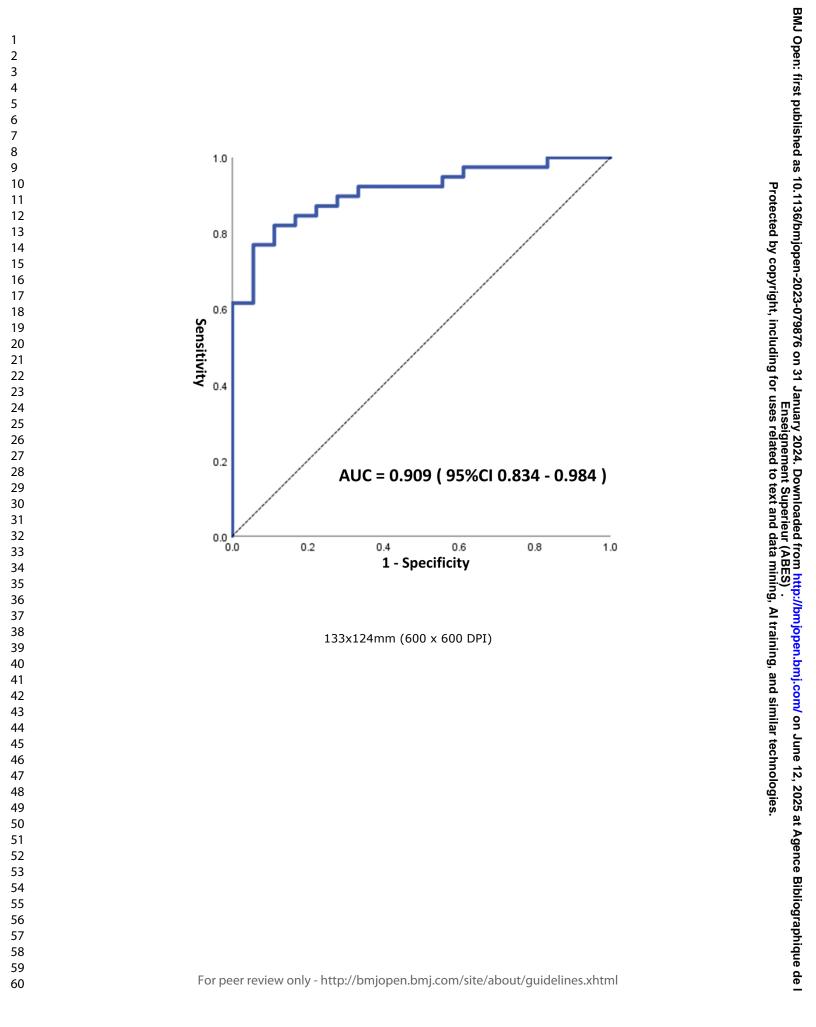
Values are mean \pm SD or n (%).

* The LAA-ostium thrombi were determined using the TEE.

The LAAMFV was calculated by halving the sum of the LAA emptying and filling velocity.

Abbreviations: $AF = atrial fibrillation; CCT = cardiac computed tomography; CHA₂DS₂-VASc = congestive heart failure, hypertension, age <math>\geq 75$ years (doubled), diabetes, previous stroke/transient ischemic attack/thromboembolism (doubled), vascular disease, age 65–74 years and sex category (female); LAA = left atrial appendage; LAAMFV = left atrial appendage mean flow velocity; LAAPD= left atrial anterior-posterior diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; TEE = transesophageal echocardiography; TIA = transient ischemic attack.

Characteristics	<i>OR</i> (95% CI)	P value
Thrombus maximum diameter, per 1 mm decrease	0.635 (0.459 ~ 0.879)	0.006
LAA-ostium thrombus	10.981 (1.702 ~ 70.831)	0.012
LAAMFV, per 1 m/s increase	47.926 (0.382 ~ 6014.699)	0.117
Abbreviations: CCT = cardiac computer tomograph	ny; CI = confidence interval; LA	A = left at
ppendage; LAAMFV = left atrial appendage mean		



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STROBE Statemer	nt—che	cklist of items that should be included in reports of observational studies			
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Title and abstract	1		January 2024. Dov Enseignement (J	Impact of left atrial appendage thrombus location on diagnost accuracy of cardiac computer tomography: a single-center case-control study
			whioaded from http://bh Superieur (ABES). ext and data mining. Al	2	Abstract Objective Cardiac computed tomography (CCT) is an emerging non-invasive modali for assessing left atrial appendage (LAA) thrombus
Introduction Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	njopen.bmj.com/ on June 12, 20 training, and similar technoloc	-	Transesophageal echocardiology (TEE) is currently the gold standard for the assessment of left atrial appendage (LAA) thrombi in patients undergoing catheter ablation of atrial fibrillation (AF)
Objectives	3		J25 at Agence Bib lies.	5	We aimed to evaluate the sensitivity of CCT in detecting LAA thrombus and to analyze the risk factors of false-negativ results
Methods			llograph	-	
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Study design	4	Present key elements of study design early in the paper including for the paper for th	ġ	5	Those who had both examinations within a 12-hour interval on the same day were retrospectively included
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	ns	5	From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital
Participants	6		d from http://bmj ur (ABES) .	5	From May 2017 to December 2022, patients were routinely scheduled for TEE and CCT before catheter ablation of AF in Guizhou Provincial People's Hospital
		(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case	open.bmj.com	5	Those who had both examinations within a 12-hour interval on the same day were retrospectively included.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	June 1	5-7	Thrombus was defined as a persistent filling defect in the 30s-delayed scans.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	2, 2025 at Agence	5-7	All patients were examined with a third-generation dual-source CT (SOMATOM Force, Siemen Healthineers, Forchheim, Germany)
Bias	9	Describe any efforts to address potential sources of bias	Bibliographique	6,7	In case of disagreement, a final joint reading was performed to achieve consensus.

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2 3 4 5 6 7 8 9 10		htTwo independent cardiologistsincludingwith more than five years ofexperience in echocardiologyevaluated the presence of LAAthrombus and measured theflow velocity. Disagreementswere resolved by consensus.thromet Supplethromet Supplethromet Supplethromet Supplethromet Supplethromet Supplethe clinical database.
11 Study size 12 13 14	10 Explain how the study size was arrived at	Edimet5All the patient characteristicsto ff Supportand images were acquired fromthe clinical database.
15 Continued on next page 16 17 18 19 20 21 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43	10 Explain how the study size was arrived at	2025 at Agence Bibliographique ogies.
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Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	t, includin	5	All the patient characteristics and images were acquired from the clinical database.
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	i January Ense	7	Continuous variables were expressed as mean ± SD deviation
		(b) Describe any methods used to examine subgroups and interactions	gnement S	7	Continuous variables were expressed as mean ± SD deviation
		(c) Explain how missing data were addressed	xt ar	N/A	
		(<i>d</i>) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	erieur (ABES) and data minin	N/A	
		(<u>e</u>) Describe any sensitivity analyses	a. Al training.	7-8	Using TEE as the reference standard, the diagnostic performance of CCT for LAA thrombi was calculated.
Results			J.c.		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	similar technolog	5	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study
			zuzo ar Agenice bibliographinque de ogles.		A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study
		(c) Consider use of a flow diagram	llograp	8	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with

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			t, including	079876 on 1	57(7.9%) LAA thrombi diagnosed by TEE were included in the study
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders		y 2024.	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study
		(b) Indicate number of participants with missing data for each variable of interest	(ABE	8 Downloaded from	A total of 726 patients (age: 61±11 years; male gender: 60.2%) with 57(7.9%) LAA thrombi diagnosed by TEE were included in the study
		(c) Cohort study—Summarise follow-up time (eg, average and total amount)	S) .	N/A	
Outcome data	15*	Cohort study—Report numbers of outcome events or summary measures over time Case-control study—Report numbers in each exposure category, or summary measures of exposure	nila	N/A 8 8	Twenty-nine (50.9%) of the thrombi were located at the LAA ostium and 28(49.1%) were in the LAA. The clinical characteristics and maximum thrombus diameter were similar between the patients.
		Cross-sectional study—Report numbers of outcome events or summary measures		ц N/A	
Main results	16	(<i>a</i>) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	hnologies	e 12, 2025	
		(b) Report category boundaries when continuous variables were categorized	•	9 at Agence Bib	By scattering the CCT results on the 2-D plane that consisted of LAAMFV and thrombus maximur diameter
		(<i>c</i>) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		liograph	
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1 2 Other analyses 3 4 5 6 7 8 9 10	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Enseign t, including for uses relat	9 3-079876 on 31 January 202	The CCT had an overall sensitivity of 68.4% and a specificity of 99.4% to the LAA thrombi (Table 1) Given that a high sensitivity is essential to exclude LAA thrombus, the CCT results of the LAA thrombi underwent further analysis
11 Discussion			emer ed ti	4 	
12 Key results 14 15 16 17 18 19 20 21 22	18	Summarise key results with reference to study objectives	ont Superieur (ABES) . to text and data mining, Al tra	n http://bmjc	We reevaluated the accuracy of CCT for detecting LAA thrombus in the 726 patients undergoing catheter ablation for AF. TEE identified 57(7.9%) patients with LAA thrombi, of which 29(50.9%) were at the LAA ostium and 28(49.1%) in the LAA
22 23 24 25 26	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	ining, and sim	12-13	Firstly, this retrospective single- center study included only patients undergoing catheter ablation for AF
27 28 29	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	la	on 11-12 Jun	Thus, the low sensitivity of CCT in our study could be presumed to
30 Generalisability 31 32 33 34 35 36 37 38	/ 21	Discuss the generalisability (external validity) of the study results	hnologies.	e 12, 2025 at Agence Bibl	Our study found that the CCT with a 30s delayed scan did not reliably exclude LAA thrombus, especially those located at the LAA ostium. We did not find any clinical characteristics associated with the thrombus location.
39 Other informa	tion			liogr	
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Funding 22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	t, including fo	079876 on 31	from the Science and Technology Support plan of Guizhou Province
Note: An Explanation a checklist is best used in	rately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups nd Elaboration article discusses each checklist item and gives methodological background and published conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmed and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at wo	enten Superieur (ABES) . ted to sext and data mining, Al training, and similar technologies.	245 Downwooded fro	of transparent reporting. The STROBE Annals of Internal Medicine at