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ORIGINAL RESEARCH

The Imaging Evaluation of Left Atrial Appendage: CT Large-Spiral Arterial Late Scan

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Purpose: Compared with retrospective ECG-gated arterial phase scan, to investigate the clinical application value of dual-source CT large-spiral arterial late scan in the imaging evaluation of left atrial appendage (LAA).

Patients and Methods: A total of 108 patients requiring LAA CT angiography (CTA) due to atrial fibrillation (AF) were selected from September 2024 to December 2024, including 52 patients in group A (Flash large-spiral arterial late scan) and 56 patients in group B (retrospective ECG-gated arterial phase scan). All patients underwent double-phase scan. The interval between the two periods is 30s. Clinical data of patients were collected, the scanning range and radiation dose received were recorded. The CT values of LAA, ascending aorta (AA) at the same level and left atrium at the largest level were measured. At the same time, evaluate other meaningful lesions within the scan range.

Results: The difference between the two groups of scanning range and radiation dose was statistically significant ($P < 0.05$). There was statistical significance in the subjective evaluation and objective evaluation of LAA filling at the first phase scanning of the two groups ($P < 0.05$). The detection of other meaningful lesions in the scanning range of group A was significantly higher than that of group B.

Conclusion: By adopting the three-generation dual-source FLASH large-pitch arterial late scan mode, the complete filling rate of the LAA was significantly improved. Not only shortened the examination time, reduced the radiation dose, but also increased the detection rate of other significant lesions within the scanning range for the patients.

Keywords: atrial fibrillation, atrial appendage, tomography, X-ray computed, radiation dose, transesophageal echocardiography

Introduction

Atrial fibrillation (AF) is the most common arrhythmia in clinical practice. Complications such as heart failure and stroke (thromboembolism) caused by AF seriously endanger people's health and cause great economic burden to society and families.[1,2] At present, the methods commonly used to treat AF and reduce the serious complications caused by AF include medical treatment, radiofrequency ablation and left atrial appendage closure (LAAC) and so on.[3,4] In order to ensure the smooth implementation of these radiofrequency ablation and LAAC treatment methods, before the operation, it is necessary to evaluate the structure and related parameters of left atrial appendage (LAA), whether there is thrombosis in LAA, etc.[5] In the past, Transesophageal Echocardiography (TEE) was widely used in clinical practice as a commonly used imaging examination method for screening LA and LAA thrombi, obtaining anatomical and adjacent tissue structure information.[6] However, due to poor tolerance in some patients, the lack of unified quantitative indicators and the fact that the reliability of the results largely depends on the operator's level have restricted clinical applications to a certain extent. In recent years, with the continuous development of CT technology, CT angiography (CTA) is increasingly used in preoperative LAA evaluation.[7] The complex anatomical structure of the LAA makes it easy for blood flow to generate vortices and slow down within it. Single-phase CT scans are difficult to accurately distinguish between thrombosis and blood stasis. Therefore, dual-phase scans are needed to improve the accuracy of diagnosis.[8] However, it has been found in clinical work that, the conventional arterial phase scan has poor LAA filling in some

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patients, and the contrast agent is relatively light in the delayed phase scan, which leads to a certain impact on the measurement of LAA morphology and related parameters before operation. At the same time, the delayed phase scan prolongs the scanning time and increases the radiation dose to the patient. Therefore, this study adopted the third-generation dual-source CT arterial late scan protocol to reduce the poor filling of contrast medium in the arterial phase of the LAA by appropriately extending the filling time of the LAA, and combined with the unique low-radiation dose large-spiral Flash scanning mode of dual-source CT, to evaluate the degree of LAA filling while expanding the scanning range and reducing the radiation dose of patients, and to explore its clinical application value.

Materials and Methods

Study Subjects

Inpatients with AF who underwent LAA CTA from September 2024 to December 2024 were enrolled. Inclusion criteria: ① Clinical diagnosis of AF requiring radiofrequency ablation or LAAC, preoperative LAA CTA examination; ② CTA image quality can meet the clinical diagnosis, and the relevant parameters can be completely and accurately measured. Exclusion criteria: ① Incomplete clinical data; ② CTA examination showed congenital heart disease, prosthetic valve, etc. The patient selection flow diagram for clarity in Figure 1. Before the examination, the patients and their families were informed of the method, purpose, content and precautions of the examination and signed the informed consent. This study was approved by our ethics committee (approval no. TDLL-202409-01).

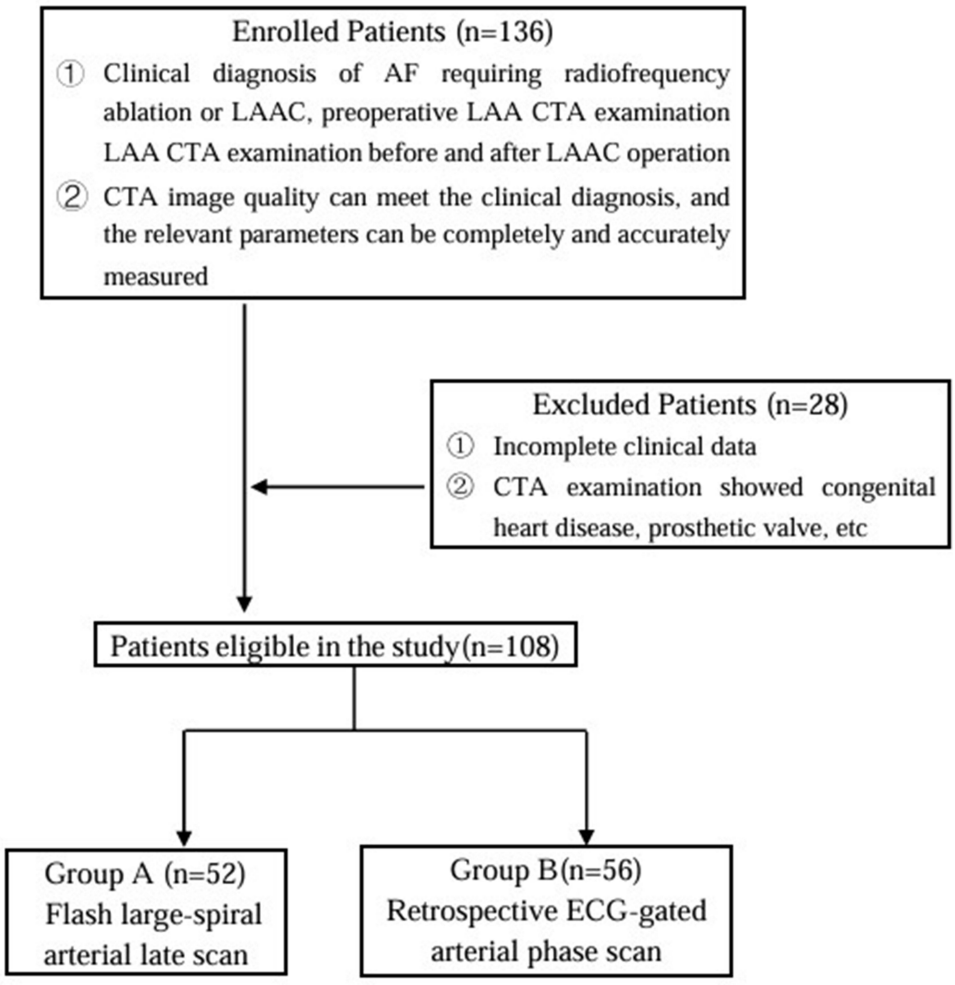

Figure 1 Patient selection flow diagram.

Scanning Equipment and Methods

All patients were scanned by third-generation dual-source CT (SOMATOM Definition FORCE, Siemens, Germany) with the arms raised supine on the examination bed and scanned in the head-foot direction. According to BMI, the tube voltage was 100–120kV and automatic tube current technology was used. The collimator width was 0.6 mm ×128, the reconstruction slice thickness was 1.0 mm, the interval was 1.0 mm, and the convolution kernel was B26f. Fifty-two patients in group A underwent Flash large-spiral arterial late scan (pitch 3.0), and 56 patients in group B underwent retrospective ECG-gated arterial phase scan. All scans were completed by holding the breath after inhalation, both groups were double-phase scanning. Because the focus is on observing the LAA, there are no requirements for heart rate. In group A, the first phase scan ranged from the thoracic entrance to the upper margin of the diaphragm, and the delayed phase was LAA range. In group B, the first phase scan ranged from 1cm below the crest of the trachea to the diaphragmatic surface of the heart, and the delayed phase was LAA range. According to the different BMI of the patients, an 18G cannula needle was used to inject 1.5 mg/kg of iodine contrast agent (iodixanol, 320 mg I/mL) and 30 mL of normal saline into the anterior elbow vein via a high-pressure syringe (Ulrich, Germany). The injection rate was 4.0–5.0 mL/s in group A and 5.0–6.0 mL/s in group B. The region of interest (ROI) was selected at the level of the maximum LA. When the threshold value in ROI reached 100 HU, Group A (arterial late phase) was delayed for 14 seconds, and Group B (arterial phase) was delayed for 6 seconds, then the first phase scan was automatically triggered, and the delay phase scan was delayed for 30s after the completion of the first phase scan.

The Scanning Range and Radiation Dose Were Calculated

After scanning, the scanning range and dose length product (DLP) of patients were recorded. The radiation dose = DLP× conversion factor [k = 0.014 mSv/(mGy·cm)]. The total radiation dose of the patient was the radiation dose of the first and delayed phase scanning.

Image Post-Processing and Analysis

The original image was transferred to the post-processing workstation for processing, analysis and measurement. Double-blind method was used to evaluate the images by two senior radiologists of circulatory system imaging, and a third radiologist was invited to conduct interventional evaluation if there was no consensus. The relevant measurements were taken as the average value of two measurements.

Subjective evaluation of LAA filling at the first-phase scanning between the two groups. Score whether the LAA of the first phase was fully filled, with 2 being fully filled and 1 being not fully filled. The window width and window level were adjusted freely, and the images of the two phases were combined and analyzed to evaluate whether there was filling defect (thrombosis).

Objective evaluation of LAA filling at the first-phase scanning between the two groups. Both groups were measured in the first-phase images. The CT value >250 HU in LA and LAA was used as the image to meet the requirements of clinical diagnosis. CT values (ROI≥1 cm2) were measured at three parts: maximum layer LAA (If not fully filled select the not fully filled area), ascending aorta (AA) at the same layer, and maximum layer LA (because of anatomical relationship and LAA are not at the same level). The ratios of LAA and AA, LAA and LA CT values (LAA_{HU}/AA_{HU}, LAA_{HU}/LA_{HU}) were also calculated.

Statistical Methods

Using SPSS 20.0 statistical software, measurement data (age, BMI, radiation dose, LAA_{HU}/AA_{HU}, LAA_{HU}/LA_{HU}, etc.) in accordance with the normal distribution in $\bar{x} \pm s$, with independent sample t test, do not meet the normal distribution in M (P25, P75), with Mann–Whitney rank sum test. Count data (gender, clinical data, score, etc.) were expressed as frequency (%) and analyzed by chi-square test. $P < 0.05$ was considered statistically significant.

Results

The General Clinical Data of the Two Groups Were Compared

A total of 108 patients were enrolled in the study, including 53 males and 55 females, aged 53–83 (68.76 ± 7.18) years, with BMI of 17.60–27.50 (22.99 ± 2.43) kg/m^2. 52 patients in group A underwent Flash large-spiral arterial late scan (pitch 3.0), and 56 patients in group B underwent retrospective ECG-gated arterial phase scan. There was no significant difference in general clinical data between the two groups ($P > 0.05$), as shown in Table 1.

The Radiation Dose and Scanning Range of the First Phase of the Two Groups Were Compared

There were significant differences in radiation dose (first phase + delayed phase) and scanning range in first phase between the two groups (Table 2). The radiation dose in group A was 2.16 ± 0.38 mSv, the radiation dose of the first phase in group A was 1.86 ± 0.32 mSv, in group A, only the first phase was scanned, the radiation dose was reduced by about 16.13%.

Subjective Evaluation of LAA Filling at the First Phase Scanning of the Two Groups Were Compared

In group A, 45 cases of LAA in the first phase were fully filled, 7 cases were not fully filled, thrombosis was observed in 2 cases of LAA during the delayed phase, and the remaining 50 cases were fully filled without definite thrombosis (Figure 2). In Group B, 34 cases of LAA in the first phase were fully filled, 22 cases were not fully filled, thrombosis was observed in 3 cases of LAA during the delayed phase, and the remaining 53 cases were fully filled without definite thrombosis (Figures 3 and 4). There was a statistically significant difference between the two groups in the subjective evaluation of complete LAA filling in the first phase ($\chi 2=9.155$, $P = 0.002$, Table 3).

Objective Evaluation of LAA Filling at the First Phase Scanning of the Two Groups Were Compared

There were significant differences in LAA_{HU}/AA_{HU} and LAA_{HU}/LA_{HU} between the two groups ($P < 0.05$, Table 4).

Table 1 The General Clinical Data of the Two Groups Were Compared

	Group A	Group B	χ^2/t Value	*p* Value
Age, y	69.58 ± 7.41	68.00 ± 6.95	1.142	0.256
Female sex[a]	27 (51.92)	28 (50.00)	0.040	0.842
BMI, kg/m^2	22.91 ± 2.42	23.06 ± 2.46	−0.321	0.749
CHA_2DS_2-VASc score	4.60 ± 1.00	4.45 ± 0.91	0.815	0.417
HAS-BLED score	3.67 ± 0.90	3.46 ± 0.95	1.168	0.246
Hypertension[a]	25 (48.08)	26 (46.43)	0.029	0.864
Diabetes[a]	11 (21.15)	14 (25.00)	0.224	0.636
Stroke[a]	13 (25.00)	15 (26.79)	0.045	0.832
Coronary heart disease[a]	14 (26.92)	18 (32.14)	0.352	0.553
Paroxysmal AF[a]	19 (36.54)	22 (39.29)	0.086	0.769

Note: [a] is represented by the number of cases (%).

Table 2 The Radiation Dose and Scanning Range of the First Phase of the Two Groups Were Compared

	Group A	Group B	t Value	*p* Value
Radiation dose, mSv	2.16 ± 0.38	6.93 ± 0.98	−33.038	0.000
The first phase scanning range, mm	225.37 ± 6.92	122.89 ± 6.32	80.412	0.000

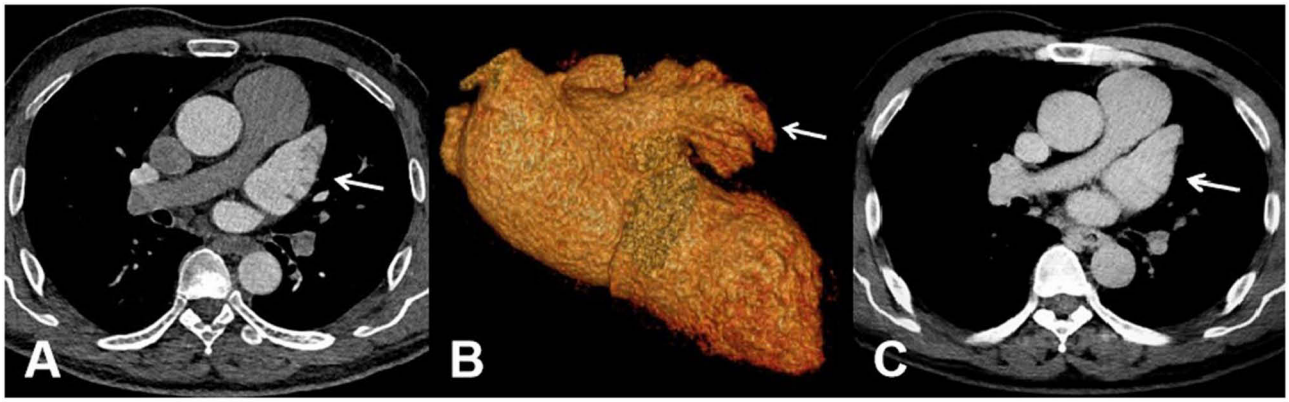

Figure 2 Female, 67 years old, Flash large-spiral arterial late scan. The distal end of LAA in the arterial late phase of CTA axial and VR images were fully filled and clearly displayed (arrow), (**A** and **B**), and the LAA in the delayed phase was completely and evenly filled (arrow), (**C**).

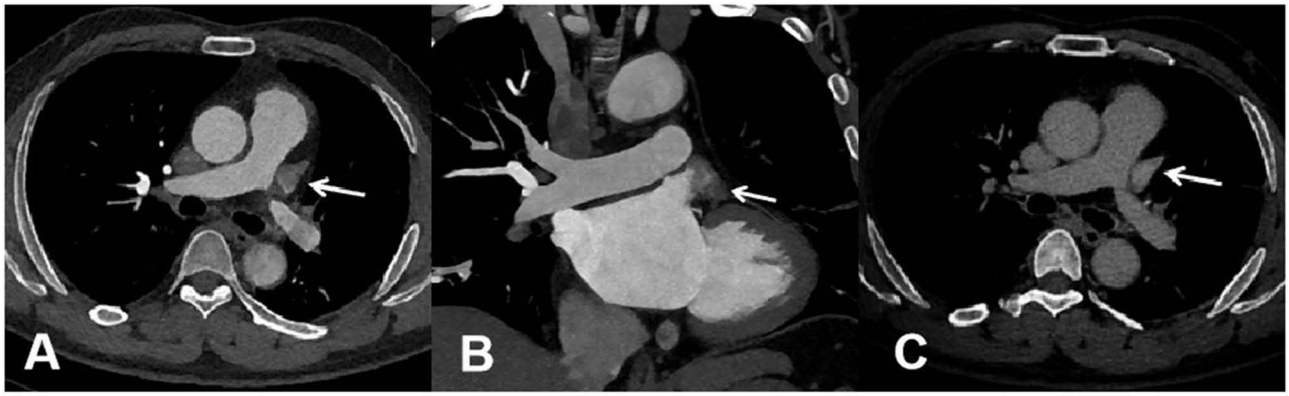

Figure 3 Male, 64 years old, retrospective ECG-gated arterial phase scan. The distal end of LAA in the arterial phase of CTA axial, coronal images were not fully filled (arrow), (**A** and **B**), and the LAA in the delayed phase was completely and evenly filled (arrow), (**C**).

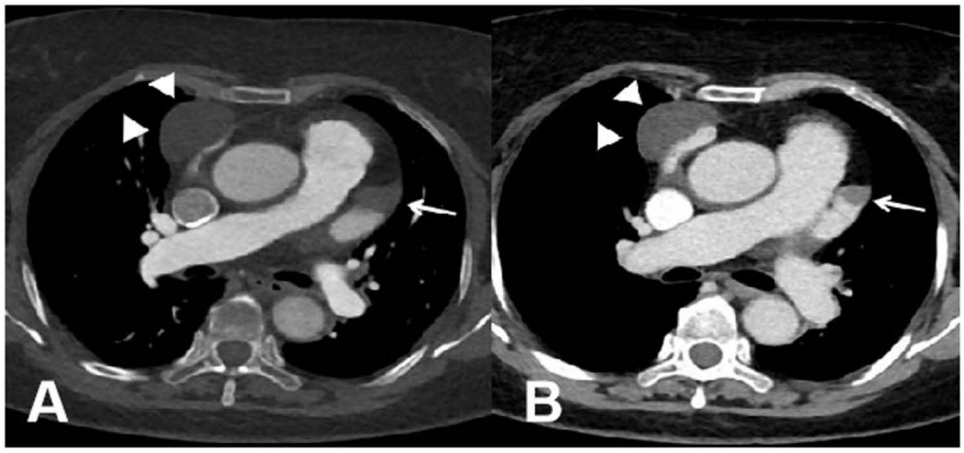

Figure 4 Male, 74 years old, LAA thrombosis. The distal end of LAA in the arterial phase of CTA was not fully filled (arrow), (**A**), and the filling defect low density shadow was found in delayed phase of LAA (arrow), (**B**). A cystic lesion at the right heart margin was also found (triangle), (**A** and **B**).

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Table 3 Subjective Evaluation of LAA Filling at the First Phase Scanning of the Two Groups Were Compared

	1 score	2 score
Group A	7 (13.46)	45 (86.54)
Group B	22 (39.29)	34 (60.71)

Table 4 Objective Evaluation of LAA Filling at the First Phase Scanning of the Two Groups Were Compared

	Group A	Group B	Z Value	*p* Value
LAA_{HU} /AA_{HU}	0.98 (0.96, 1.01)	0.97 (0.24, 1.00)	−2.164	0.030
LAA_{HU} /LA_{HU}	0.98 (0.97, 0.99)	0.96 (0.24, 0.99)	−2.106	0.035

Other Meaningful Lesions Found in CTA

All of 108 patients, in group A, there were 2 cases of pulmonary embolism, 6 cases of pleural effusion, 12 cases of pneumonia with attasis, 3 cases of moderate or above coronary artery stenosis, and 1 case of lung cancer (Figure 5). In group B, there were 2 cases of pleural effusion, 6 cases of pneumonia with attasis, 2 cases of moderate or above coronary artery stenosis, and 1 case of cystic lesion in the right heart margin.

Discussion

AF is a common electrical activity disorder arrhythmia in clinical practice. Its main feature is that the atria lose effective contraction, resulting in blood stasis in the LAA, thereby increasing the risk of thrombosis and subsequently triggering serious complications such as stroke.[9] The treatment strategies for AF include two major categories: controlling heart rhythm and preventing stroke. The main method for controlling heart rhythm is radiofrequency ablation, while the main methods for preventing stroke are long-term oral anticoagulants and LAAC, etc.[10,11] For patients with symptomatic AF who have both a high risk of stroke and an indication of ablation, the one-stop treatment of "radiofrequency ablation +LAAC" may benefit

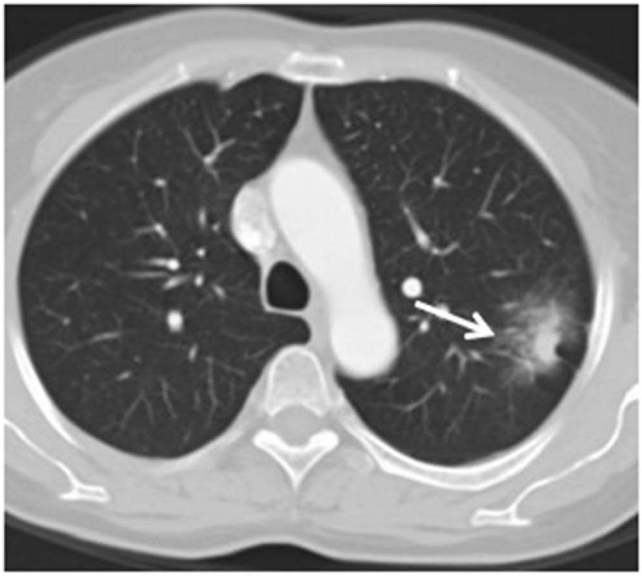

Figure 5 Male, 79 years old, unexpected finding of lung cancer. Mixed ground glass nodule shadow in the left upper lobe of the lung, which was confirmed as lung cancer by pathology (arrow).

more clinically.[12] For this reason, it is particularly important to clarify the position and shape of the pulmonary vein orifice, the connection between the pulmonary vein and LA, the three-dimensional structure of LA and LAA before the operation, evaluate the adjacent surrounding tissue structure or the tissue structure on the surgical access, especially whether there is thrombosis in LA and LAA. Many scholars have recommended TEE as a common imaging method to detect LA and LAA thrombus, obtain anatomical and structural information of adjacent tissues.[6] However, TEE is a semi-invasive examination and is poorly tolerated by some patients. At the same time, the lack of unified quantitative indicators, the reliability of the results largely depends on the level of the operator, so the clinical application is limited. In recent years, with the continuous development and popularization of CT technology, CT has the advantages of fast, convenient and non-invasive, combine with a variety of post-processing techniques that are objective and can be measured quantitatively, it can not only determine the position and shape of the pulmonary vein orifice, the connection between the pulmonary vein and LA, the three-dimensional structure of LA and LAA before the operation, evaluate the adjacent surrounding tissue structure or the tissue structure on the surgical access, but also the dual-phase scanning can also greatly improve the identification efficiency of LAA poor filling, LA and LAA thrombus,[13,14] which is gradually widely used in clinical practice. A total of 108 patients in this study were scanned by dual-source CT before operation, which clearly showed the location and size of the pulmonary vein orifice, the pulmonary vein-LA junction, LA and LAA three-dimensional structure. Moreover, dual-source CT was used to diagnose LAA thrombus in 5 cases, which provided more objective and valuable information for clinical practice.

For LAA imaging, most literature recommends a scanning range from 1cm below the crest of the trachea to the diaphragmatic surface of the heart, and the scanning method adopts prospective or retrospective electrocardiogated scanning.[15] Gilhofer et al[16] adopted Toshiba 320 CT, where the scanning range was from the heart to the diaphragmatic surface (14–16cm), and the radiation dose was about 2.4mSv. In this study, 52 patients in group A underwent Flash large-spiral scanning, the first phase scan ranged from the thoracic entrance to the upper margin of the diaphragm, and the delayed phase was LAA range, the total radiation dose of the two-phase scan was about 2.16 ± 0.38 mSv. Retrospective ECG-gated arterial phase scan was performed in 56 patients in group B, the first phase scan ranged from 1cm below the crest of the trachea to the diaphragmatic surface of the heart, and the delayed phase was LAA, the total radiation dose of the two-phase scan was about 6.93 ± 0.98 mSv. In the first phase scan, the scanning range of group A was 225.37 ± 6.92 mm, and the scanning range of group B was 122.89 ± 6.32 mm, although the scanning range was expanded by about 84%, the radiation dose was significantly lower. Meanwhile, most clinical AF patients are elderly, often complicated with heart, lung and other diseases, and chest CT conditions often need to be evaluated before surgery. In this study, large-spiral Flash scanning was used in group A, scan ranged from the thoracic entrance to the upper margin of the diaphragm, basically covers the entire chest, not only evaluate the basic conditions of pulmonary veins, LA, left ventricle and LAA, roughly evaluate the coronary arteries, but also evaluate the conditions of both lungs, pulmonary artery and heart, providing more imaging evidence for accurate preoperative evaluation. In group A of this study, 2 cases of pulmonary embolism (Drug treatment was carried out), 6 cases of pleural effusion (Among them, there were 2 cases of thoracic cavity puncture and drainage), 12 cases of pneumonia with attasis (anti-inflammatory treatment), 3 cases of moderate or above coronary artery stenosis (Among them, one case later received a coronary artery stent), and 1 case of lung cancer (Subsequently, the corresponding lung segmentectomy was surgically removed) were also found. The detection of other meaningful lesions in the scan range of group A was significantly higher than that of group B.

Studies have shown that the complex anatomical structure of the LAA makes it easy for blood flow to generate vortices and slow down within it, hemodynamic changes lead to the remodeling of LAA, causing LAA to lose its normal contraction and relaxation functions. As a result, LAA cannot be emptied in time, causing blood to accumulate here and making LAA prone to thrombosis.[17,18] The delay phase is mainly used to identify LAA poor filling and LAA thrombus, but the delay phase will also increase the patient's radiation dose. However, LAA complete filling in the first stage can exclude the LAA poor filling and LAA thrombus, so it is not necessary to perform delayed-phase scanning. Therefore, only for those with LAA poor filling in the first phase, delayed-phase scanning limited to the LAA area is performed, which will reduce the radiation dose of most patients, group A of this study showed a reduction in radiation dose of about 86.54% of patients and a reduction of about 16.13%. In this study, group A used large-spiral Flash scanning and the first phase scan delay was 8 s longer than that in group B, and the injection rate was slightly slowed down to maintain sufficient contrast agent concentration in the LAA, allowing

relatively enough time for the LAA to be fully filled. When the LAA was complete filling in the first phase, the scan could be completed, which saved the examination time and reduced the radiation dose of patients.

Most previous studies mainly relied on CT arterial phase images for the three-dimensional reconstruction of the LAA and the measurement of related parameters.[19,20] However, this method has limitations in some AF patients. For instance, due to the uneven distribution of contrast agent during the arterial phase, the LAA fails to be fully filled, resulting in unclear display of its internal structure such as the muscle trabeculae, thereby affecting the accurate preoperative assessment of the shape and the number of lobes of the LAA, as well as the measurement accuracy of related parameters. It may even interfere with the differential diagnosis between the muscle trabeculae and potential thrombi. Prolonging the filling time of the LAA appropriately during CT scan, that is, using arterial late scan, can significantly reduce the poor filling of the LAA caused by insufficient filling time, and greatly improve the complete filling rate of the LAA. In this study, 45 (86.54%) of patients were completely filled by arterial late scan in group A at the first phase, and 34 (60.71%) were completely filled by arterial scan in group B at the first phase, indicating that the LAA full filling rate was significantly increased when the arterial late phase scanning was used. At the same time in the first phase of the image of the two groups of LAA_{HU}/AA_{HU}, LAA_{HU}/LA_{HU} comparison of statistical differences, suggesting that the first phase of arterial late scanning LAA full filling rate is higher, which is shown as high-density film close to AA and LA, the clinical LAA reconstruction and the measurement of related parameters, thrombosis identification is of great significance.

Limitations

Certain limitations apply to this study. First, TEE is the gold standard for detecting LAA thrombus. The absence of TEE-based validation weakens the diagnostic credibility of the findings. Second, in the early stage of this study, based on a small sample test, 14s delay was adopted for first-phase scanning in group A, and the effect of different delay times was not compared. The delay time was different according to the parameters of the CT equipment used, the selection of scanning mode, the concentration of contrast agent and the injection speed, and the patients' own cardiac function, etc. The specific optimal delay time of first phase needs further study. In addition, this study was a single-center research with a small sample size. It did not compare with TEE and only evaluated the advantages of CT, to enhance feasibility and diagnostic accuracy, large-sample and multi-center studies can continue.

Conclusion

In summary, for the first phase of LAA imaging, arterial late scanning and appropriately extending the LAA filling time can significantly improve the LAA full filling rate. For those with complete LAA filling in the first phase, there is no need for delayed scanning. Combined with dual-source CT large-pitch Flash scanning, while expanding the scanning range, it saves the examination time, reduces the radiation dose of patients, and under the premise of meeting the relevant preoperative requirements, it improves the detection rate of meaningful lesions in patients, which is worthy of clinical application and promotion.

Ethics Approval and Informed Consent

This study was approved by the Research Ethics Committee of Tangdu Hospital, Fourth Military Medical University (approval no. TDLL-202409-01). Written informed consent was obtained from all participants and in accordance with the principle of the Helsinki Declaration.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted.

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Disclosure

The authors declare that they have no conflicts of interest for this work.

References

1. Manning WJ, Silverman DI, Keighley CS, et al. Transesophageal echocardiographically facilitated early cardioversion from atrial fibrillation using short-term anticoagulation: final results of a prospective 4.5-year stud. *J Am Coll Cardiol*. 1995;25(6):1354–1361. doi:10.1016/0735-1097(94)00560-D
2. Hindricks G, Potpara T, Dagres N; ESC Scientific Document Group, et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS): the Task Force for the diagnosis and management of atrial fibrillation of the European Society of Cardiology (ESC) Developed with the special contribution of the European Heart Rhythm Association (EHRA) of the ESC. *Eur Heart J*. 2021;42(5):373–498. doi:10.1093/eurheartj/ehaa612
3. Li F, Sun JY, Wu LD, et al. The long-term efficacy and safety of combining ablation and left atrial appendage closure: a systematic review and meta-analysis. *J Cardiovasc Electrophysiol*. 2021;32(11):3068–3081. doi:10.1111/jce.15230
4. Buysschaert I, Viaene D. Clinical impact of preprocedural CT-based 3D computational simulation of left atrial appendage occlusion with amulet. *J Interv Cardiol*. 2021;2021:9972228. doi:10.1155/2021/9972228
5. Liu XW, Tian X, Hu J, et al. Factors associated with left atrial appendage filling defects on early-phase cardiac computed tomography in patients with nonvalvular atrial fibrillation: a case-control study. *Quant Imaging Med Surg*. 2023;13(2):720–734. doi:10.21037/qims-22-146
6. Tzikas A, Holmes Jr DR, Gafoor S, et al. Percutaneous left atrial appendage occlusion: the Munich consensus document on definitions, endpoints, and data collection requirements for clinical studies. *Europace*. 2017;19(1):4–15. doi:10.1093/europace/euw141
7. Sun C, Lv J, Liu M, et al. Different scanning protocol to assess left atrial appendage thrombus in patients with atrial fibrillation by cardiovascular computed tomography. *Sci Rep*. 2024;14(1):30414. doi:10.1038/s41598-024-81708-0
8. Korsholm K, Berti S, Iriart X, et al. Expert recommendations on cardiac computed tomography for planning transcatheter left atrial appendage occlusion. *JACC Cardiovasc Interv*. 2020;13(3):277–292. doi:10.1016/j.jcin.2019.08.054
9. Okada M, Inoue K, Tanaka N; Osaka Cardiovascular Conference (OCVC)-Arrhythmia Investigators, et al. Impact of left atrial appendage flow velocity on thrombus resolution and clinical outcomes in patients with atrial fibrillation and silent left atrial thrombi: insights from the LAT study. *Europace*. 2024;26(5):euae120. doi:10.1093/europace/euae120
10. Durmaz E, Karpuz MH, Bilgehan K, et al. Left atrial thrombus in patients with atrial fibrillation and under oral anticoagulant therapy; 3-D transesophageal echocardiographic study. *Int J Cardiovasc Imaging*. 2020;36(6):1097–1103. doi:10.1007/s10554-020-01811-x
11. Yang W, Zhao Q, Yao M, et al. The prognostic significance of left atrial appendage peak flow velocity in the recurrence of persistent atrial fibrillation following first radiofrequency catheter ablation. *J Thorac Dis*. 2021;13(10):5954–5963. doi:10.21037/jtd-21-1363
12. Matsumoto Y, Morino Y, Kumagai A, et al. Characteristics of anatomy and function of the left atrial appendage and their relationships in patients with cardioembolic stroke: a 3-dimensional transesophageal echocardiography study. *J Stroke Cerebrovasc Dis*. 2017;26(3):470–479. doi:10.1016/j.jstrokecerebrovasdis
13. Tacher V, Sifaoui I, Kharrat R, et al. The use of cardiac computed tomography angiography in the assessment of percutaneous left atrial appendage closure - Review and experts recommendations endorsed by the Société française d'imagerie cardiaque et vasculaire diagnostique et interventionnelle. *Diagn Interv Imaging*. 2021;102(10):586–592. doi:10.1016/j.diii.2021.05.010
14. Wu X, Sun F, Ma S, et al. Application of computed tomographic angiography and echocardiography in predicting left atrial appendage thrombosis in patients with non-valvular atrial fibrillation. *Cardiovasc J Afr*. 2023;34(4):231–236. doi:10.5830/CVJA-2022-052
15. Mosleh W, Sheikh A, Said Z, et al. The use of cardiac-CT alone to exclude left atrial thrombus before atrial fibrillation ablation: efficiency, safety, and cost analysis. *Pacing Clin Electrophysiol*. 2018;41(7):727–733. doi:10.1111/pace.13353
16. Gilhofer TS, Abdellatif W, Nicolaou S, et al. Cardiac CT angiography after percutaneous left atrial appendage closure: early versus delayed scanning after contrast administration. *Diagn Interv Radiol*. 2021;27(6):703–709. doi:10.5152/dir.2021.20349
17. Cui J, Xia SJ, Tang RB, et al. Morphology and location of thrombus and sludge in patients with non-valvular atrial fibrillation. *BMC Cardiovasc Disord*. 2024;24(1):398. doi:10.1186/s12872-024-04073-w
18. Liu J, Yu T, Tan C, et al. How the trabeculae protrude within the left atrial appendage is the key factor affecting thrombosis in patients with atrial fibrillation. *Int J Cardiovasc Imaging*. 2023;39(11):2259–2267. doi:10.1007/s10554-023-02933-8
19. Zhao MZ, Chi RM, Yu Y, et al. Value of detecting peri-device leak and incomplete endothelialization by cardiac CT angiography in atrial fibrillation patients post Watchman LAAC combined with radiofrequency ablation. *J Cardiovasc Electrophysiol*. 2021;32(10):2655–2664. doi:10.1111/jce.15222
20. Kaafarani M, Saw J, Daniels M, et al. Role of CT imaging in left atrial appendage occlusion for the WATCHMAN™ device. *Cardiovasc Diagn Ther*. 2020;10(1):45–58. doi:10.21037/cdt.2019.12.01