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RESEARCH

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The efficiency of endocardial suture occlusion of the left atrial appendage at a single institution: MICs vs. sternotomy

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Abstract

Background Most thrombi originate from the left atrial appendage (LAA), preventing thromboembolic stroke is an important aspect of stroke prevention. Previous studies have found that LAA closure is beneficial for preventing thrombosis. Currently, surgical procedures can achieve LAA closure by closing the endocardium or epicardium. LAA endocardial suture technique is performed concomitantly during sternotomy cardiac surgery but can also be performed during right minimally invasive cardiac surgery (MICS).

Aims This study aims to evaluate the efficacy of left atrial appendage closure (LAAC) with MICS.

Methods A total number of 74 patients who underwent LAAC during valve operation between 2017 and 2021 were retrospectively analyzed in this study. LAA was closed by continuous suture through the endocardium of the left atrium during cardiac surgery. 42 patients performed LAA endocardial suture during MICS, while 32 patients performed with the same LAAC technique during sternotomy. Patients underwent cardiac computed tomography (CT) follow-up after surgery to verify the completeness of the LAAC. The heart structure and function were recorded by echocardiography Transthoracic echocardiography (TTE), and the heart rhythm was recorded by electrocardiogram.

Results The LAA closure procedure was successful in 26 cases (81%) in the sternotomy group and 20 cases (48%) in the right minimally invasive group. Residual shunting (failed LAA closure) was more common in the right minimally invasive group ($p = 0.003$), and no correlation was found between residual shunting and left atrial (LA), left ventricular end-diastolic diameter (LVDD), and left ventricular ejection fraction (LVEF). The incidence of leaks was not associated with mitral valve replacement or valvuloplasty.

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Conclusions Compared to sternotomy, residual shunting after MICS was more common. CT imaging analysis of 22 patients with failed closure in the MICS group showed that residual shunting was mainly concentrated on margins of the suture (anterior superior and posterior inferior) (86%), with a middle area accounting for 3 (14%). Based on this finding, reinforcing the suture margins may significantly reduce the incidence of incomplete closure.

The clinical trial number : KY-2023-001.

Keywords Endocardial suture occlusion, Left atrial appendage closure, Minimally invasive cardiac surgery, Cardiac computed tomography, Left atrial appendage patency

Introduction

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia worldwide. Ischemic stroke is the most detrimental complication of AF; 15–20% of all ischemic strokes are caused by AF. It is especially vigilant that the stroke incidence in patients with valvular atrial fibrillation is 17 times higher than in those without atrial fibrillation [1]. Strokes caused by AF are often more severe than those caused by atherosclerosis. It has been reported that the majority of cardiogenic thrombi originate from the left atrial appendage [2]. Therefore, it is necessary to consider closing LAA during valve surgery to reduce thromboembolic risk. Although several types of atrial appendage closure techniques are already available, there is still no standard surgical procedure. Surgical LAA occlusion can be performed through the endocardium of the left atrium or from the epicardium, with the latter being achieved through a median sternotomy, using sutures, clamps, and suture holders [3]. However, in minimally invasive cardiac surgery, the application of the epicardial suturing technique is relatively challenging (Fig. 1), left atrial appendage clip occlusion is an effective and durable technique in MICS, but it increases left surgical incision and Increases the cost of treatment. Therefore, oversew is still a common technique because it is inexpensive (the only cost is the suture), reliable, and safe [4].

Minimally invasive techniques are increasingly being adopted due to their advantages of less trauma, less blood loss, and better cosmetic outcomes [5].

Therefore, it is necessary to study the effectiveness of endocardial suturing during minimally invasive cardiac surgery (MICS). In recent years, cardiac CT has become more advantageous tool for assessment of the LAA [6–8]. The aim of our study was to compare the success rate of LAAC with different approaches and to assess the location of the leaks on cardiac CT after LAAC.

Methods

In the years 2017 to 2021, the primary inclusion criterion for the retrospective analysis was elective cardiac surgery in adult valvular patients with atrial fibrillation. The exclusion criteria for the study were renal insufficiency and a known allergy to the contrast medium, 174 consecutive adult valvular patients, with persistent atrial fibrillation, underwent valve surgery concurrent with LAAC by one surgical team at the Department of Cardiovascular Surgery, the First Affiliated Hospital of Jinan University. All of them were invited to a follow-up CT examination to assess the outcome of LAAC, and 74 accepted the invitation and participated in the study.

Surgery: 32 patients underwent valve surgery concurrently with LAAC, and 42 patients underwent right minimally invasive valve surgery concurrently with LAAC. The appendage was closed from the inside using a double-layer running Polypropylene suture. The first layer of suture was located at the initial site of the atrial appendage orifice, and the suture should be gentle to avoid tears in the endocardium. The second layer of suture should be parallel to the first layer (Fig. 2).

Visual analysis of the left atrium: After valve surgery and LAAC, all patients underwent cardiac computed tomography (CT) and 2D transthoracic echocardiogram (TTE). The mean follow-up time was 18 months after surgery. The protocol of the evaluation of LAAO (Left Atrial Appendage Occlusion) is no different from coronary artery CTA. CT scans and image analyses were all performed on a Toshiba 320-slice helical CT (Aquilion One), with a tube current of 600–800 mAs, and a tube voltage of 100–120 kV, The beam collimation was 0.625 mm. Follow-up CT scans were performed using a dual-source CT scanner system with non-ionic contrast material(60 ml), and 30-ml solution was administered intravenously at a rate of 5 ml/s using a power injector. Cardiac phase reconstruction images were taken usually at late atrial diastole, corresponding to approximately 70–80% of the RR interval. The LAA patency was analyzed by two experienced independent readers. Complete occlusion of the LAA after LAAO was defined as a radiodensity of < 100 HU, contrast opacification of < 25% of the left atrium, and LAAC without any leak. LAA contrast-filling (CF) in cardiac CT was defined as radiodensity > 100 HU of the LAA separated from the suture occlusion, or contrast opacification > 25% of the left atrium with the presence of any LAA opacification compared with the pre-LAAO cardiac CT (Fig 3).

Statistical analysis: A multivariate logistic model identified predictors of the leak, LA diameters, LAA diameters,

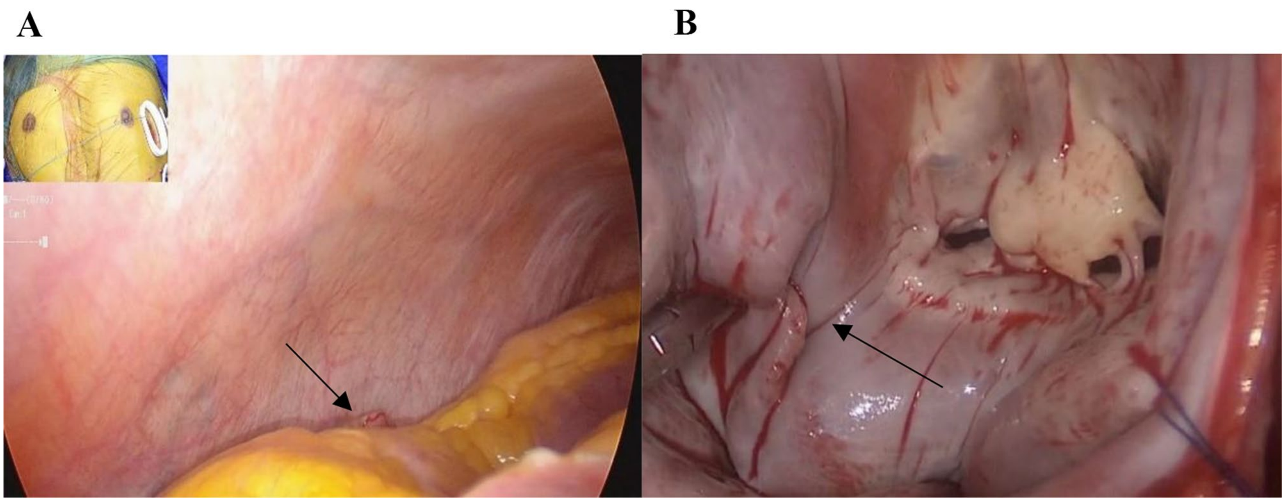

Fig. 1 **a**: In right mini-thoracotomy, epicardium of LAA is incomplete exposed(arrow), **b**: endocardium of left atrium provides very good visibility of the base of the atrial appendage (arrow)

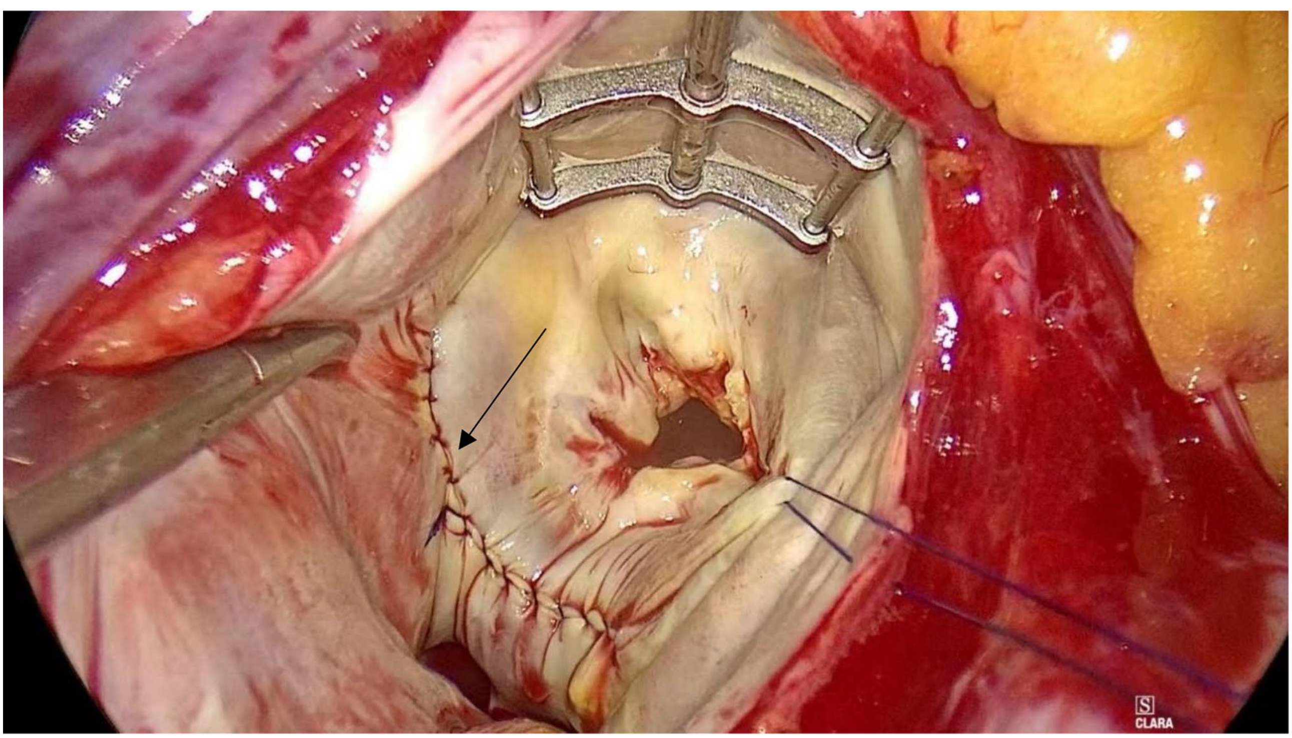

Fig. 2 The appendage was closed from the inside using a double-layer running Polypropylene suture(arrow)

and LV function parameters. A p-value of < 0.05 was considered significant. Utilizing SPSS 16.0 statistical software, quantitative data was analyzed through the T-test, while non-grade qualitative data was compared utilizing the Chi-Square Test. For samples exceeding 40 with theoretical frequencies ranging from greater than 1 to less than 5, a corrected Chi-Square Test was employed. In cases where the theoretical frequency was less than 1, Fisher's Exact Test was applied. The rank data was assessed via the rank sum test. A p-value of less than 0.05 was considered statistically significant.

Result

Baseline characteristics and LAA occlusion procedures

Patient characteristics at baseline are shown in Table 1. The population studied comprised 74 patients. The mean age was 60.53 ± 10.35 years, BMI was 23.16 ± 3.57 kg/m2. This study did not find a correlation between age ($p = 0.141$) and BMI($p = 0.258$) of those with complete

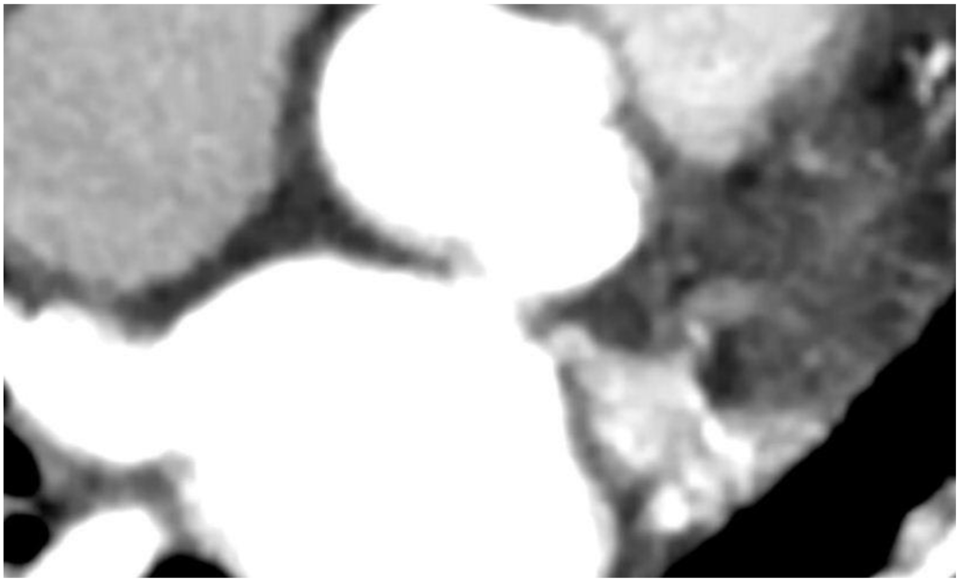

Fig. 3 LAA patency related to an antero-superior leak

Table 1 Baseline

	Mean (sd) success LAAC VS LAAC patency p-value		
Age, yrs		60.53 ± 10.35	0.141
BMI, kg/m2		23.16 ± 3.57	0.258
Pre-procedural TTE			
LA(mm)		53.16 ± 8.85	
LVDD(mm)		47.79 ± 8.63	
LVEF(%)		60.93 ± 8.61	
Surgical approach			
Sternotomy	32	43%	
Right-side MICS	42	57%	

BMI, body mass index; TTE, transthoracic echocardiography; LA, left atrial(mm); LVDD, left ventricular diastolic diameter(mm); LVEF, left ventricular ejection fraction(%); MICS, minimally invasive cardiac surgery

LAAC and incomplete LAAC. Among them, 32 patients underwent sternotomy for left atrial appendage closure, and 42 patients had left atrial appendage closure performed by minimally invasive cardiac surgery (MICS). Before surgery, transthoracic ultrasound showed a left atrial (LA) size of 53.16 ± 8.85 mm, a left ventricular diastolic diameter (LVDD) of 47.79 ± 8.63 mm, and a left ventricular ejection fraction (LVEF) of 60.93 ± 8.61%. The procedures of the study include mitral valvuloplasty + tricuspid valvuloplasty + LAAC; mitral valvuloplasty + tricuspid valvuloplasty + radiofrequency ablation + LAAC; aortic valve and mitral valve replacement + tricuspid valvuloplasty + LAAC; mitral valve replacement + tricuspid valvuloplasty + radiofrequency ablation + LAAC and mitral valve replacement + tricuspid valvuloplasty + LAAC. The mean X-ray exposure for each CT study was 17.51 ± 16.81 months.

Table 2 CT follow

	Sternotomy	Right-side MICS	*p*-value
Incomplete LAAC(%)	6(19%)	22(52%)	0.003
Location of residual shunt-postero-inferior and Antero-superior(%)	3(50%)	19(86%)	0.091

CT, computed tomography; LAAC, Left atrial appendage closure; MICS, minimally invasive cardiac surgery

Table 3 TTE follow

Surgical Technique	TTE		LAA patency($n = 22$)	Complete LAAC($n = 20$)	*P*-value
MICS	Pre-procedural	LA(mm)	52.00 ± 5.26	53.68 ± 7.88	0.426
		LVDD(mm)	46.85 ± 7.50	44.32 ± 6.45	0.247
		LVEF(%)	62.90 ± 7.15	60.00 ± 7.71	0.215
	Post-procedural	LA(mm)	43.40 ± 5.87	42.38 ± 6.40	0.054
		LVDD(mm)	45.05 ± 5.95	43.95 ± 4.68	0.509
		LVEF(%)	62.70 ± 6.32	61.95 ± 6.16	0.701

LAAC, Left atrial appendage closure; MICS, minimally invasive cardiac surgery; TTE, transthoracic echocardiography; LAA, left atrial appendage; LA, left atrial; LVDD, left ventricular diastolic diameter; LVEF, left ventricular ejection fraction

Findings on follow-up

The follow-up results are summarized in Tables 2, 3 and 4. A total of 28 patients (38%) with left atrial appendage reconnection were confirmed by CTA, including 6 (29%) in the sternotomy group and 22 (52%) in the MICS group. Left atrial appendage reconstitution was more common in the MICS group compared to the median sternotomy group. Analysis of CTA in the MICS group revealed that leakage flow neck mainly occurred at both ends of the suture line in 19 cases (81%), while

Table 4 MICS patient data

ID	Age (year)	Gender	NYHA	Dysfunction of mitral valve	Operation	Postop-erative rhythm	Anticoagulation
1	51	F	II	RHD	MVR (mechanical valve 27 mm) + TVP + LAAC	AF	warfarin
2	50	F	II	RHD	MVR (mech anical valve 25 mm) + TVP + mini-maze + LAAC	sinus	warfarin
3	50	F	III	RHD	MVR (mech anical valve 25 mm) + TVP + mini-maze + LAAC	sin us	warfarin
4	48	M	III	RHD	MVR (mechanical valve 25 mm) + TVP + mini-maze + LAAC	AF	warfarin
5	55	F	III	RHD	MVR (mechanical valve 25 mm) + TVP + mini-maze + LAAC	sinus	warfarin
6	48	M	II	RHD	MVR (mechanical valve 25 mm) + TVP + mini-maze + LAAC	AF	warfarin
7	48	M	III	RHD	MVR (mechanical valve 25 mm) + TVP + mini-maze + LAAC	AF	warfarin
8	41	M	II	RHD	MVRI mechanical valve 25 mm) + TVP + LAAC	sinus	warfarin
9	65	F	II	RHD	MVR (biop rost hetic valve 25 mm) + TVP + mini-maze + LAAC	sinus	no
10	73	F	II	RHD	MVR (biop rost hetic valve 25 mm) + TVP + mini-maze + LAAC	AF	rivaroxaban
11	64	M	II	Degeneration	MVR (biop rosthetic valve 25 mm) + TVP + mini-maze + LAAC	sinus	no
12	70	F	IV	RHD	MVR (bioprosthetic valve 25mmE + TVP + LAAC	AF	rivaroxaban
13	73	F	III	RHD	MVR (bioprosthetic valve 25 mm) + LAAC + excision of myxoma	sinus	no
14	72	M	III	Degeneration	MVP (32 mm) + TVP + mini-maze + LAAC	AF	rivaroxaban
15	40	F	II	Degeneration	MVP(32 mm) + TVP + mini-maze + LAAC	sinus	no
16	54	F	IV	Degeneration	MVP (32 mm) + TVP + mini-maze + LAAC	AF	rivaroxaban
17	72	F	II	Dilatation	MVP (30 mm) + TVP + LAAC + ASD	AF	rivaroxaban
18	69	M	II	Degeneration	MVP (30 mm) + TVP + LAAC	AF	rivaroxaban
19	59	M	II	Degeneration	MVP (28 mm) + TVP + LAAC	AF	rivaroxaban
20	55	F	II	RHD	MVR (mech anical valve 25 mm) + TVP + mini-maze + LAAC	sinus	warfarin
21	71	F	III	RHD	MVR (mechanical valve 25 mm) + TVP + mini-maze + LAAC	sinus	warfarin
22	57	F	II	Degeneration	MVR (mechanical valve 25 mm) + TVP + mini-maze + LAAC	sinus	warfarin
23	49	F	III	RHD	MVR (mech anical valve 25 mm) + TVP + LA TH + LAAC	AF	warfarin
24	67	M	I	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	AF	warfarin
25	56	F	II	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	AF	warfarin
26	51	F	III	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	AF	warfarin
27	51	F	III	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	AF	warfarin
28	51	F	III	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	AF	warfarin
29	51	F	III	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	AF	warfarin
30	51	F	III	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	AF	warfarin
31	53	F	II	RHD	MVR (mechanical valve 25 mm) + TVP + LAAC	sinus	warfarin
32	76	M	III	Degeneration	MVR (bioprosthetic valve 27 mm) + TVP + LAAC	AF	rivaroxaban
33	76	M	III	Degeneration	MVR (bioprosthetic valve 27 mm) + TVP + LAAC	AF	rivaroxaban
34	71	F	IV	RHD	MVR (bioprosthetic valve 25mmE + TVP + mini-maze + LAAC	sinus	no
35	71	F	IV	RHD	MVR (bioprosthetic valve 25mmE + TVP + mini-maze + LAAC	sinus	no
36	70	F	III	RHD	MVR (bioprosthetic valve 25mmE + TVP + mini-maze + LAAC	AF	rivaroxaban
37	76	F	II	RHD	MVR (bioprosthetic valve 25 mm) + TVP + LAAC	AF	Rivaroxaban
38	67	M	II	Degeneration	MVP (30 mm) + TVP + LAAC	sinus	no

Table 4 (continued)

ID	Age (year)	Gender	NYHA	Dysfunction of mitral valve	Operation	Postoperative rhythm	Anticoagulation	
39	59	F	II	Dilatation	MVP (28 mm) + TVP + LAAC	AF	rivaroxaban	
40	72	F	III	RHD	MVR (bioprosthetic valve 25 mm) + TVP + mini-maze + LAAC	sinus	no	no cerebral infarction symptom during follow-up
41	71	F	IV	RHD	MVR (bioprosthetic valve 25 mm) + TVP + mini-maze + LAAC	sinus	no	
42	65	F	II	RHD	MVR (bioprosthetic valve 25 mm) + TVP + mini-maze + LAAC	sinus	no	

ID:1–20: complete left atrial appendage conclusion; ID:21–42: left atrial appendage patency

M: male; F: female. MVP: mitral valvuloplasty; MVR: mitral valve replacement; TVP: tricuspid valvuloplasty; LAAC: left atrial appendage closure; RHD: Rheumatic Heart Disease; AF: atrial fibrillation; ASD: atrial septal defect; LATH: left atrial thrombus

the middle area accounted for only 3 (19%). The follow-up TTE In the MICS group was analyzed in Table 3. Follow-up TTE was performed simultaneously with CTA, The prevalence of leaks did not relate to LA(mm) (pre-procedural 52.00 ± 5.26 VS 53.68 ± 7.88, $p = 0.426$; pose-procedural 43.40 ± 5.87 VS 42.38 ± 6.40, $p = 0.054$), LVDD(mm)(pre-procedural 46.85 ± 7.50 VS 44.32 ± 6.45, $p = 0.247$; Pose-procedural 45.05 ± 5.95 VS 43.95 ± 4.68, $p = 0.509$), or LVEF(%) (pre-procedural 62.90 ± 7.15 VS 44.32 ± 6.45, $p = 0.215$; pose-procedural $62.70 \pm 6{,}32$ VS 61.95 ± 6.16, $p = 0.701$). This study did not find a correlation between postoperative LA, LVDD, and LVEF size with left atrial appendage reconstitution. The incidence of leaks was not associated with mitral valve replacement or valvuloplasty($p = 0.603$).

In MICS group, NYHA, type of dysfunction of the mitral valve, operation, postoperative rhythm, and present anticoagulation are presented in Table 4. Rheumatic Heart Disease and degeneration are the most common type of dysfunction of the mitral valve. Surgical treatment for mitral valve dysfunction includes mitral valvuloplasty and mitral valve replacement. There are 11 patients (26%) in this study who underwent mitral valvuloplasty, while 31 patients who underwent mitral valve replacement (74%). Lifelong anticoagulation therapy is indicated in patients with mechanical valves or with atrial fibrillation. The requirement for anticoagulation in patients with incomplete LAA closure is contentious. Consequently, in this study, three patients with incomplete LAA closure who did not have atrial fibrillation or mechanical valve replacement did not receive anticoagulant therapy.

Discussion

In Germany, almost 50% of mitral valve surgery was done without sternotomy, right-side MICS has since become a well-established alternative to sternotomy in valve procedures [9]. In MICS procedures, left atrial appendage (LAA) closure is typically achieved through endocardial suturing. An effective occlusion of LAA reduces the risk of ischemic stroke or systemic embolism after surgery [10]. Surgical closure is suitable to every anatomical LAA in contrast to the transcatheter closure technique [11]. In the most recent 2020 ACC/AHA Guidelines, treatment of the LAA concomitantly with cardiac surgery is considered reasonable(2a, level of evidence B-NR(nonrandomized) while the recommendation of 2021 ESC/ EACTS Guidelines has increased to IIa(should be considered, level of evidence B) [12, 13]. LAAC is encouraged in the guidelines, while MICS has been widely used in cardiac surgery, so it is necessary to determine the effectiveness of endocardial suture occlusion of the left atrial appendage during minimally invasive cardiac surgery.

Transesophageal echocardiogram (TEE) is the most common imaging modality for follow-up assessments, but cardiac CT was reported to be more sensitive than TEE in the assessment of residual leak into the LAA after LAAC because it has excellent spatial resolution and 3-dimensional assessment facilitates more sensitive detection and clarifies the mechanisms of leakage [8]. Additionally, its non-invasive and better comfort level provide advantages over transesophageal echocardiography. Several pilot studies suggest that cardiac CT may be superior to TEE for the detection during follow-up [6, 14–16]. There are limited controlled studies on LAA closure under minimally invasive surgical approaches (MICS) and median sternotomy. This study is a post-procedural CT finding in patients undergoing endocardial suture occlusion of the left atrial appendage via different surgical approaches. Our study found that postoperative LAA recanalization is common in the MICS group, and the success rate of LAA closure under MICS is similar to that of transcatheter LAA occlusion (48% vs. 44–61%) [17]. In cases of LAA recanalization under MICS, we found that the main sites of recanalization concentrate at the ends of the suture margins (anterior superior and posterior inferior). Based on this finding, reinforcing the suture margins may significantly reduce the incidence of incomplete closure. More attempts can be made to improve the technology in the future, such as reinforcing the suture margins with gaskets.

MICS VS sternotomy

MICS is an essential surgical technique in cardiac surgery. Therefore, it is crucial to enhance the effectiveness of left atrial appendage (LAA) closure under MICS. However, we achieved a 48% success rate in LAA closure under MICS, whereas the success rate of LAA suture in the sternotomy group reached 81%. ($p=0.003$), LAA patency is more common in patients treated with MICS. Incomplete occlusion is higher than that reported by Grzegorz Hirnle in his previous study on MICS-mediated LAA closure followed by TEE [11]. The difference may be related to the higher sensitivity of computed tomography angiography (CTA) compared to transesophageal echocardiography in detecting LAA recanalization [6, 14, 15, 18]. In TEE, the diagnosis of recanalization requires observing explicit leakage flow jets, thereby reducing its sensitivity to leaks. In contrast, CTA only requires observing the contrast agent concentration within the LAA rather than leakage flow jets to diagnose LAA recanalization, which compares favorably to TEE in terms of fewer subjective errors and higher sensitivity.

LAA patency

LAA patency was based on measurements of the attenuation coefficient within the LA and the LAA. Our result confirmed that LAA patency is common in MICS on the arterial phase CT imagine (52%). The technique of left atrial appendage closure by suturing the inner lining of the left atrial appendage appears to be a simple technique but often leads to failed suturing under MICS. The reason may be related to the unique three-dimensional structure of the atrial appendage [4, 17].What's more, In the MICS group, in addition to higher recanalization, we found that the recanalization sites were concentrated at the ends of the suture margins. Compared with the sternotomy group, MICS has greater limitations in surgical operating space, longer instruments, and smaller incisions, which increase the difficulty of surgical operations [9]. When suturing the upper and lower margins of the atrial appendage orifice, the difficulty of suturing is greater, resulting in a higher incidence of incomplete closure (recanalization) on both sides of the suture margin after closure. Since the course of the circumflex artery is not visible within the left atrium, shallow sutures are often used during the closure of the left atrial appendage to avoid damaging the circumflex artery, which can also lead to a high rate of incomplete closure.

Surgical exclusion of the LAA can be successfully closed by using the clip, it can be performed concomitantly during sternotomy, but also can be performed during MICS, the complete exclusion of the left atrial appendage was achieved 92.2% [19]. However, clip LAA occlusion devices are not suitable for all patients. Clip closure is not indicated in the following conditions: reoperation, known LAA-thrombus, patients from the intensive care unit, history of pericarditis, and recent myocardial infarction(<90d) [19]. Moreover, in developing countries, the value of surgical consumables is an important consideration, the cost of devices for clip(25000RMB) is much higher than suture(160RMB) in China. Although endocardial suture occlusion of the left atrial appendage during MICS does not add additional trauma and is inexpensive, our study found that this technique results in frequent recanalization. At present, there is still no ideal method that is both economical and effective for MICS.

In some previous studies on percutaneous left atrial appendage occlusion, it was found that the size of LA and LVEF affect the success rate of occlusion [15]. However, in our study, we did not find that the success rate was related to LA, LVDD, and LVEF. Mitral valve replacement or mitral valvuloplasty did not influence the amount of LAA patency($p=0.603$). Although the high rate of recanalization is a common problem after LAAC, the treatment of LAA patency after surgical or Percutaneous closure of the left atrial appendage is still controversial, incomplete closure without anticoagulant may lead to stroke. During follow-up, 3 patients with LAA patency were found to have no anticoagulation, but left atrial thrombus and stroke were not found in these patients. The sample size of this study was small, and further studies are needed to determine whether LAA patency increases the risk of stroke.

Limitation

This is a single-center retrospective analysis study, the small sample size may not be enough to illustrate the true situation of this technique. A follow-up rate of 43% may underestimate the incidence of complications such as stroke. Finally, the clinical outcome correlated with the CT finding of incomplete closure requires further follow-up studies for confirmation.

Conclusion

LAA patency is common on CT after endocardial suture occlusion of the atrial appendage during valve operation via MICS. The most common defect location is the ends of the suture margins (anterior superior and posterior inferior). further studies are desirable to promote the LAAC technique during MICS. Reinforcing the suture margins with gaskets may help to improve the success rate of LAAC via MICS.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions
C.H. to the acquisition of data, extract and analysis data, drafting and revising the article and take part in the study design. Y.L. is responsible for the radiomics feature extraction of CCTA. Y.Z. contributes to statistical processing, modeling construction. S.S. and J.H. contribute to propose clinical problems and point out the key factors affecting the studied diseases. H.L. review the manuscript and give the guidance on Intelligent processing technology. X.Z. takes full responsibility for the work, instructs the design and writing, provides clinical and information processing expertise. All authors read and approved the final manuscript.

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

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the principles of the Helsinki. The study was approved by the Ethics Committee of the First Affiliated Hospital of Jinan University. This study is a retrospective study and the contents of the study do not involve personal privacy, the Ethics Committee of the First Affiliated Hospital of Jinan University waived the requirement for written informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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