Efficacy of four different left atrial appendage closure techniques during cardiac surgery—A transesophageal echocardiography follow-up study

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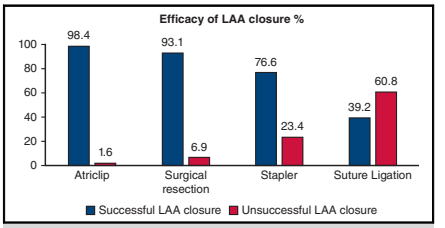
ABSTRACT

Objective: Closure of the left atrial appendage (LAA) is a routine part of atrial fibrillation ablation surgery and significantly reduces stroke rates. Different LAA-closure techniques are used in cardiac surgery with variable results reported. We therefore evaluated the efficacy of 4 different LAA-closure techniques in patients undergoing cardiac surgery.

Methods: In total, 149 patients who underwent concomitant LAA closure during cardiac surgery between 2015 and 2019 were included in this retrospective transesophageal echocardiography study. Four different LAA-closure techniques were evaluated: LAA clipping (n = 62), suture ligation (n = 28), stapler resection (n = 30), and surgical LAA excision (n = 29). Successful LAA closure was defined as absence of LAA perfusion and absence of a stump greater than 10 mm.

Results: The mean patients age was 68.7 ± 9.4 years; 61.7% were male. No complications related to LAA closure were observed. Mean follow-up was 36.5 ± 8 months. Transesophageal echocardiography follow-up showed the following LAA closure success rates: LAA clip 98.4%, surgical excision 93.1%, stapler resection 76.6%, and suture ligation 39.2%. Suture ligation resulted in a high rate of recanalization (50%) and residual stumps (10.8%), whereas stapler resection resulted in a high rate of residual stumps (23.4%). Overall, 4 patients (2.7%) had a stroke during follow-up. In detail, 2 of 27 (7.4%) patients with unsuccessful LAA closure had a stroke, whereas 2 of the 122 (1.6%) patients with successful LAA closure had a stroke.

Conclusions: In our study, LAA clipping and surgical LAA excision proved to be both successful LAA-closure methods. External LAA ligation and stapler resection resulted in low rates of successful LAA closure and should be avoided. (JTCVS Techniques 2024;26:43-9)



Efficacy of different LAA-closure methods.

CENTRAL MESSAGE

In our transesophageal echo study, LAA clipping and surgical LAA excision proved to be successful LAA closure methods, whereas external ligation and stapler resection had low rates of successful LAA closure.

PERSPECTIVE

LAA closure is an essential part of AF treatment and has been shown to significantly reduce the incidence of stroke in patients with AF undergoing cardiac surgery. However, different LAA-closure methods with variable results have been used in the past. We evaluated the efficacy of 4 different LAA-closure methods and found LAA clipping and surgical resection to be the most effective techniques.

Atrial fibrillation (AF) is the most common form of supraventricular arrhythmia[1,2] and is associated with a 5-fold increased risk of stroke.[3,4] The prevention of thromboembolic events is therefore an important part of the management of patients with AF. The efficacy of oral anticoagulation for this purpose is well established, but it

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Abbreviations and Acronyms
AF = atrial fibrillation
CABG = coronary artery bypass grafting
LAA = left atrial appendage
LAAOS = Left Atrial Appendage Occlusion Study
TEE = transesophageal echocardiography

is also associated with numerous drawbacks, highlighting the need for alternative, lower-risk, effective, and more sustainable long-term methods of stroke prophylaxis.[5]

Because the majority of thrombi in cardioembolic stroke originate from the left atrial appendage (LAA), it seems reasonable that an exclusion of the atrial appendage from the systemic blood circulation could protect against cerebral infarction.[6] In patients with AF undergoing cardiac surgery, LAA closure can be easily performed concomitantly with cardiac surgeries.[7]

However, there has long been a paucity of evidence on the association between atrial appendage closure and long-term stroke risk reduction in patients with AF undergoing cardiac surgery, and there are only few studies evaluating the effectiveness of atrial appendage closure in preventing thromboembolic events in these patients.

The Left Atrial Appendage Occlusion Study (LAAOS) trials have provided important results in this area. After LAAOS II showed that simultaneous atrial appendage closure during cardiac surgery was not associated with any additional risk,[8] LAAOS III demonstrated that the combination of surgical atrial appendage closure and oral anticoagulation can significantly reduce the incidence of stroke compared with oral anticoagulation alone.[9] Therefore, concomitant atrial appendage closure in combination with oral anticoagulation therapy provides additional protection against stroke.

Many different procedures are available for surgical LAA closure, with widely varying and sometimes unsatisfactory results.[10] However, as inadequate or incomplete LAA closure may increase the risk of thromboembolic events,[11,12] it is necessary to evaluate which form of LAA treatment results in safe closure, in both the short and long term.

In the present study, we therefore investigated the 4 different surgical techniques of LAA closure performed at our center during the study period and evaluated their long-term closure success using transesophageal echocardiography (TEE). We also investigated whether successful atrial appendage closure can reduce the incidence of stroke in this study population.

METHODS

Overall, 281 patients underwent surgical LAA closure at our institution between May 2015 and December 2019. A total of 149 patients had TEE during follow-up and were included in this retrospective study. Four different LAA-closure methods were used in the study population: LAA closure with LAA clip (AtriClip PRO; AtriCure) (n = 62), external LAA suture ligation using PROLENE Purse string suture around the base of the LAA (n = 28), LAA resection with stapler (Covidien Endo GIA) (n = 30), and LAA excision followed by LAA base suture (n = 29). Successful LAA closure was defined as absence of LAA perfusion and absence of a residual stump greater than 10 mm in TEE. The choice of LAA closure technique was at the surgeon's discretion and also related to the surgical approach. The LAA clip was used in all cases of minimally invasive mitral and tricuspid surgery via right anterolateral minithoracotomy. All LAA closure techniques were used in patients undergoing sternotomy.

For AF treatment, 130 (87.2%) patients received additional surgical ablation, whereas 19 (12.8%) patients were treated with LAA closure alone. In patients undergoing surgical AF ablation, an isolated pulmonary vein isolation was used in 54 patients, whereas a complete left atrial lesion set was used in 51 patients. A biatrial lesion set was performed in 25 patients. Cryoablation (cryoICE Cryoablation Probe; AtriCure) was used as the energy source in 56 patients, whereas bipolar radiofrequency (Cardioblate BP2 Device and Cardioblate Surgical Ablation System Generator from Medtronic or the Isolator Synergy Access Clamp EMT1 from AtriCure) in 74 patients. The study received institutional review board approval on December 12, 2022 (Ethics Committee of the Hamburg Medical Association 2020-10183).

Follow-up Echocardiography

All patients underwent TEE with assessment of the LAA closure during follow-up. In 64 patients, the TEE was performed during clinical routine examination, whereas 85 patients received elective TEE assessment for evaluation of successful LAA closure. The mean TEE follow-up duration was 36.5 ± 8 months (range, 12-73 months). LAA was assessed in multiple views (Seward JB 1993). Color Doppler was used over the LAA to assess the presence of flow between the left atrium and the occluded LAA. LAA occlusion was classified as (1) successful closure; (2) patent LAA; and (3) residual LAA. Patent LAA was defined as a persistent communication between the LAA and the left atrium. Residual LAA was defined as a residual stump or pouch remaining in the LAA >10 mm in maximum length after closure. Unsuccessful LAA closure was defined as the presence of a patent LAA, an LAA with persistent flow into the appendage, or a residual LAA. Successful closure was defined as the absence of all of the aforementioned. All TEEs were reanalyzed by the investigators, with particular emphasis on the assessment of the LAA. The investigators were blinded to the LAA closure technique at the time of TEE analysis.

Statistical Analysis

All statistical analyses were performed using SPSS statistical software, version 21.0 (IBM Corp). Continuous values are expressed as mean ± standard deviation and were compared with the Student *t* test when appropriate; otherwise, a Mann-Whitney *U* test was used. Categorical variables are presented as frequencies and percentages and were compared using the χ^2 test or Fisher exact test (<5 values per cell), as appropriate.

RESULTS

Patient Characteristics

The mean age of the patients was 68.7 ± 9.4 years; 61.7% were male. The mean left atrial volume was 105.3 ± 47.1 mL, whereas the mean left ventricular ejection fraction was 53.6 ± 11.2%. The mean duration of AF was 2.8 ± 4.1 years, and 40.9% of patients had preoperative paroxysmal AF. Sixteen (10.7%) patients had a history of

TABLE 1. Patient baseline demographics

	N = 149
Age, y	68.7 ± 9.4
Sex, male, n (%)	91 (61.7)
LA volume, mL	105.3 ± 47.1
AF duration, y	2.8 ± 4.1
LVEF, %	53.6 ± 11.2
Paroxysmal AF, n (%)	61 (40.9)
Previousstroke, n (%)	16 (10.7)
Renal insufficiency, n (%)	29 (19.5)
Coronary artery disease, n (%)	55 (36.9)
Arterial hypertension, n (%)	124 (83.2)
Hyperlipidemia	58 (38.9)
Diabetes mellitus	23 (15.4)
EuroSCORE II, %	2.5 ± 1.79

LA, Left atrial; *AF*, atrial fibrillation; *LVEF*, left ventricular ejection fraction; *EuroSCORE*, European System for Cardiac Operative Risk Evaluation.

stroke. Arterial hypertension was present in 83.2% of patients, whereas diabetes mellitus was diagnosed in 15.4%. A total of 58 (38.9%) patients had hyperlipidemia, and 55 (36.9%) had coronary artery disease. The mean European System for Cardiac Operative Risk Evaluation II was 2.5% ± 1.8%. Detailed baseline characteristics of the patients are shown in Table 1.

Procedural Data

The surgical procedures performed included isolated aortic valve replacement in 21 patients. Isolated coronary artery bypass grafting (CABG) was performed in 19 patients and combined CABG and aortic valve replacement in 7 patients. Isolated mitral valve surgery was performed in 51 patients (via minimally invasive access in 40 patients), whereas a combined mitral and tricuspid surgery was performed in 23 patients (via minimally invasive access in 13 patients). Aortic valve surgery combined with mitral valve surgery was performed in 11 patients. Other procedures were performed in 17 patients. Mean crossclamp time was 82.4 ± 26.7 minutes, and mean cardiopulmonary bypass time was 133.7 ± 44.6 minutes.

There were no major complications related to LAA occlusion and ablation. There were no intraoperative deaths. In-hospital mortality was 1.3%. One-year survival was 94.6%. Two (1.3%) patients suffered a perioperative stroke. The postoperative rate of new permanent pacemaker implantation rate was 6.0%.

Evaluation of LAA Closure Success

The distribution of different LAA closure techniques with concomitant procedures is shown in Table 2. See Figure 1 for a graphical abstract of the study. LAA clipping with the AtriClip resulted in a successful closure rate of 98.4% (61/62). In 1 patient (1.6%), a residual stump of more than 10 mm was observed at follow-up TEE. Stapler resection of the LAA had a successful LAA closure rate of 76.6% (23/30), with a residual stump more than 10 mm in 7 patients (23.4%). External suture ligation had a success rate of 39.2%. Residual LAA perfusion was observed in 50% (14/28) of patients, and/or a residual stump more than 10 mm was observed in 10.8% of patients. Surgical excision followed by suturing of the LAA base showed a successful LAA closure rate of 93.1% (27/29). Two patients (6.8%) had a residual stump of more than 10 mm on TEE follow-up. Detailed success rates of different LAA closure techniques are displayed in Figure 2. Mechanisms of unsuccessful LAA closure are shown in Table 3. Exemplary TEE of successful LAA closure (using AtriClip) is shown in Figure 3, whereas a TEE scan of unsuccessful LAA closure with perfusion of the LAA in a patient after external LAA ligation is displayed in Figure 4.

Clinical and echocardiographic parameters were evaluated if they were associated with successful LAA closure (Table 4). The use of AtriClip, stapler excision and surgical resection were all associated with successful LAA closure, with success rates ranging from 98.4% for AtriClip to 76.6% for stapler excision. Patients undergoing CABG procedures had a significantly greater rate of unsuccessful LAA closure. Left atrial volume, concomitant aortic valve replacement or CABG, and left ventricular ejection fraction did not significantly influence LAA closure success.

TABLE 2. Distribution of different LAA closure methods and concomitant procedures

	LAA clip, n = 62	Suture ligation, n = 28	Stapler resection, n = 30	Surgical resection, n = 29
CABG	2	13	2	2
AVR	3	3	10	8
CABG/AVR	1	2	2	2
MVR	42	1	5	3
MVR/TVR	13	2	3	5
AVR/MVR	1	3	2	4
Other	0	4	6	5

LAA, Left atrial appendage; *CABG*, coronary artery bypass grafting; *AVR*, aortic valve replacement; *MVR*, mitral valve repair/replacement; *TVR*, tricuspid valve repair.

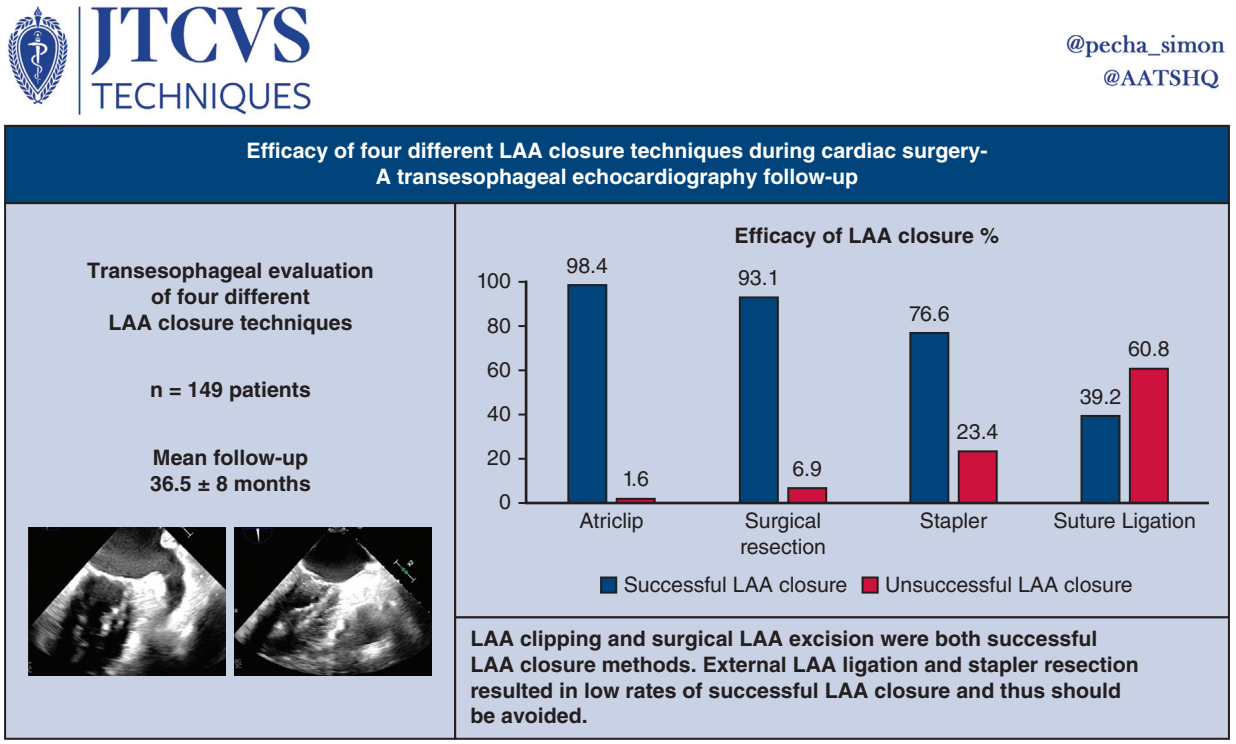

FIGURE 1. In this study, transesophageal echocardiography was used to evaluate success of four different LAA closure techniques with a mean follow-up of 36.5 months. LAA clipping and LAA excision were both successful LAA closure methods with success rates of 98.4% and 93.1%, respectively. External LAA ligation and stapler resection resulted in low rates of successful LAA closure. *LAA*, Left atrial appendage.

Follow-up

During the mean follow-up of 36.5 ± 8 months, 4 patients (2.7%) had a stroke. Two of the 27 (7.4%) patients with unsuccessful LAA closure had a stroke, whereas 2 of 122 (1.6%) patients with successful LAA closure had a stroke. These results show a numerically greater rate of stroke in patients with unsuccessful LAA closure, but the difference is not statistically significant ($P = .150$).

Both patients with stroke and unsuccessful LAA closure had an embolic stroke during follow-up. One of the patients was treated with an intraoperative LAA ligation with residual LAA perfusion during TEE follow-up. The other patient had an intraoperative stapler resection with a 19-mm residual LAA at TEE. Both patients were on direct oral anticoagulation at the time of stroke.

In the group of patients with successful LAA closure, 1 patient treated intraoperatively with an LAA clip experienced an intracranial bleeding 3 months postoperatively while being on oral anticoagulation. This patient was also diagnosed with an arteriovenous malformation, which may have also contributed to the cerebral bleeding complication. Another patient with a successful LAA resection had

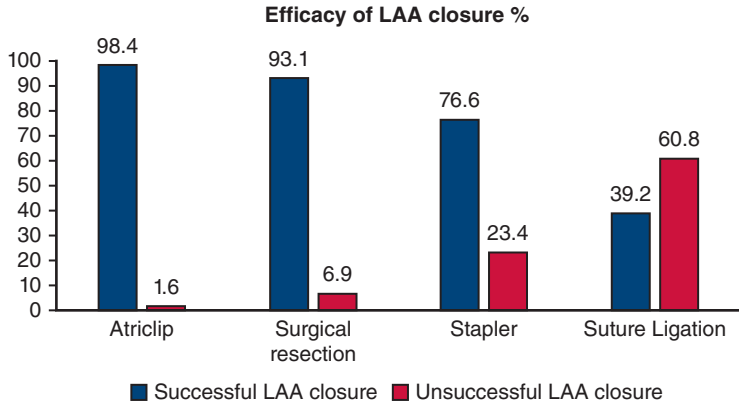

FIGURE 2. Efficacy of different LAA closure methods. *LAA*, Left atrial appendage.

TABLE 3. Mechanisms of unsuccessful LAA closure

LAA closure method (n = 149)	Successful closure, n (%)	Perfusion of LAA, n (%)	Stump >10 mm, n (%)
AtriClip (n = 62)	61 (98.4)	0	1 (1.6%)
Stapler resection (n = 30)	23 (76.6)	0	7 (23.4)
External suture ligation (n = 28)	11 (39.2)	14 (50)	3 (10.8)
Surgical excision (n = 29)	27 (93.1)	0	2 (6.8)

LAA, Left atrial appendage.

an embolic stroke during follow-up. This patient was taking oral anticoagulation with coumadin at the time of stroke.

In general, 76.5% of patients were on oral anticoagulation at the latest follow-up. In the group of patients with successful LAA closure, the rate of oral anticoagulation was 74.3%, whereas the rate of oral anticoagulation at last follow-up in patients with unsuccessful LAA closure was 81.5%.

DISCUSSION

The results of our study are important in the context of stroke prevention in cardiac surgery patients with AF. The high success rates of LAA clipping and surgical excision verified by TEE suggest that these methods should be preferred for LAA closure. The lower efficacy of LAA ligation and stapler resection, especially with the high recanalization rates in suture ligation, indicates these methods might not be as reliable.

The concept of LAA occlusion for stroke prevention was first described in 1947 when Hellerstein and colleagues[13] performed LAA occlusion in a canine model and suggested a therapeutic role in patients with rheumatic mitral disease. Then, in 1949, Madden[14] described the first human cases of LAA resection, marking the beginning of surgical approaches to LAA closure. Since then, LAA closure has undergone significant development, including various surgical and endovascular techniques.

Despite various techniques, the success rates of surgical LAA closure have been variable as the result of the variable anatomy of the LAA. The goal of achieving a smooth endocardial surface has not been reliably achieved with various endocardial or epicardial approaches.[15] A meta-analysis by Dawson and colleagues[16] highlighted that most studies reported only a 55% to 66% successful LAA occlusion rate. The authors even suggested that incomplete exclusion may actually cause harm to the patient. For example, an investigation of 137 patients with LAA occlusion by Kanderian and colleagues[10] showed a success rate of only 40%. The study group analyzed 3 different techniques with similar results to our study: suture and stapler exclusion do not result in sufficient LAA occlusion. However, our experience showed a greater success rate for LAA excision (93% vs 73%) and even for suture exclusion (39% vs 23%) and stapler exclusion (76% vs 0%). In addition, our study is the first comparative analysis to include TEE analysis of 4 different LAA occlusion techniques highlighting the superiority of the LAA clip with a success rate of 98.4%. Furthermore, we have shown the technical safety of the investigated LAA closure techniques without seeing any LAA closure related complications in our patient population.

Notably, in our study was no significant difference in stroke rates between patients with successful and unsuccessful LAA closure. Similar findings were reported by Kanderian and colleagues.[10] Although we found numerical differences in stroke rates between the 2 groups (successful LAA closure 1.6%; vs unsuccessful LAA closure 7.4% $P = .150$), there was no statistically significant difference. This might on the one hand be related to the relatively low number of events in both groups and, on the other hand, this finding may suggest that additional factors other than the efficacy of LAA closure may influence the risk of stroke after cardiac surgery. Such factors may include patient-specific characteristics (eg, arteriovenous malformations) or concomitant medical therapies (presence and type of anticoagulation). Anticoagulation alone reduces the risk of stroke in patients with AF by about two-thirds.[17]

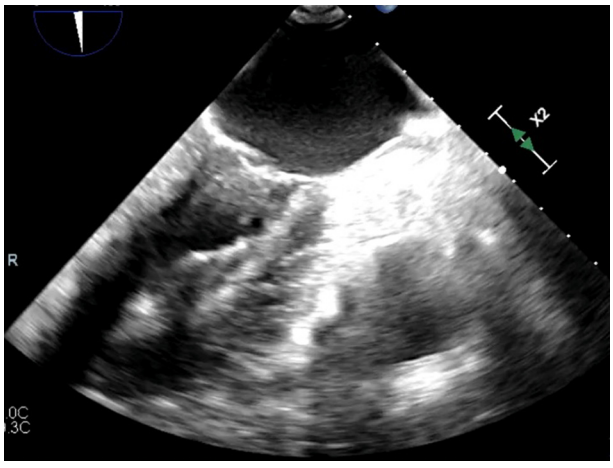

FIGURE 3. Transesophageal echocardiography showing successful left atrial appendage closure after clip.

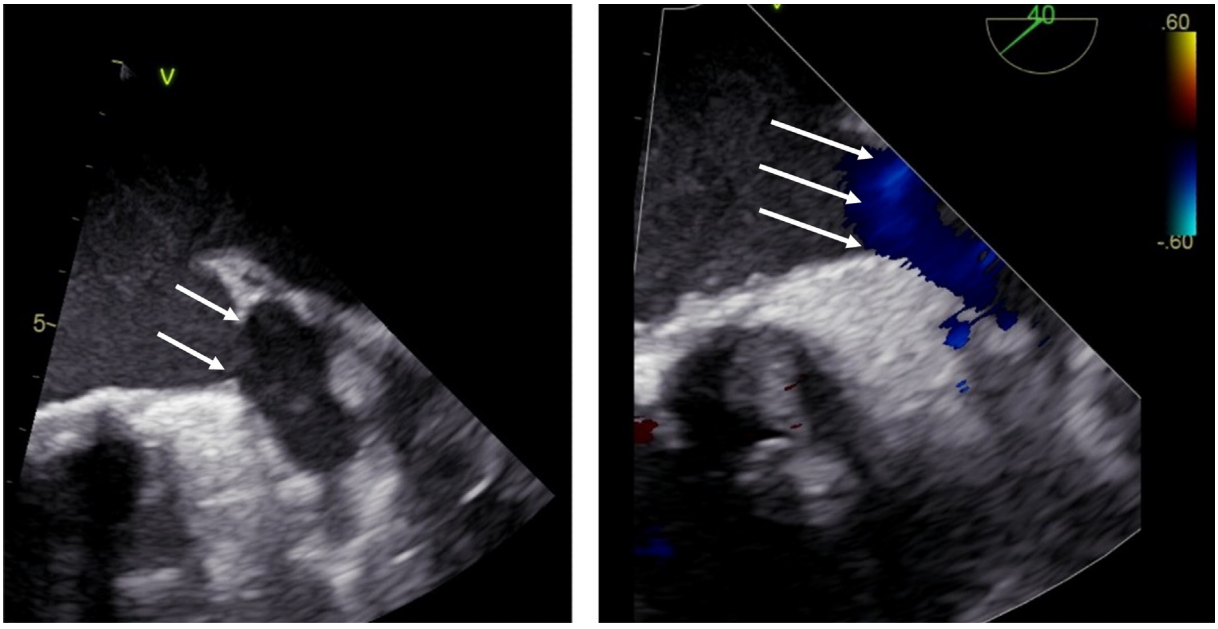

FIGURE 4. TEE showing unsuccessful LAA closure after external LAA ligation. Spontaneous contrast is shown in the LAA and Doppler color flow from LA into the LAA (*white arrows*). *TEE*, Transesophageal echocardiography; *LAA*, left atrial appendage.

LAAOS III provided information that concomitant LAA occlusion in addition to oral anticoagulation reduces the risk of stroke by about one third.[9] Effective surgical occlusion of the LAA, when added to anticoagulation, therefore provides additional protection against stroke. The importance of LAA closure has been implemented in the new 2023 American College of Cardiology/American Heart Association/American College of Clinical Pharmacy/Heart

TABLE 4. Variables related to successful and unsuccessful LAA closure

(n = 149)	Successful closure (n = 122)	Unsuccessful closure (n = 27)	*P* value
AtriClip (n = 62)	61 (98.4)	1 (1.6%)	**<.001**
Stapler resection (n = 30)	23 (76.6)	7 (23.4)	**<.001**
External suture ligation (n = 28)	11 (39.2)	17 (60.8)	.18
Surgical excision (n = 29)	27 (93.1)	2 (6.9)	**<.001**
Age	70.6 ± 7.7	68.2 ± 9.7	.23
LA volume, mL	102.3 ± 46.8	114.3 ± 48.5	.23
LVEF, %	53.9 ± 11.3	52.4 ± 10.9	.52
CABG, n (%)	21 (17.2)	12 (44.4)	**.004**
MVR, n (%)	78 (63.9)	12 (44.4)	.08
AVR, n (%)	35 (28.7)	10 (37.0)	.49
Double valve procedure, n (%)	28 (23.0)	8 (29.6)	.46
Coronary artery disease, n (%)	41 (33.6)	14 (51.9)	.08
Renal insufficiency, n (%)	24 (19.7)	8 (18.5)	.89
Hyperlipidemia, n (%)	44 (36.1)	14 (51.9)	.14
EuroSCORE II, %	2.5 ± 1.79	2.4 ± 1.29	.29

P value in bold is significant. *LA*, Left atrial; *LVEF*, left ventricular ejection fraction; *CABG*, coronary artery bypass grafting; *MVR*, mitral valve repair/replacement; *AVR*, aortic valve replacement; *EuroSCORE*, European System for Cardiac Operative Risk Evaluation; *LAA*, left atrial appendage.

Rhythm Society guidelines for the diagnosis and management of AF, which upgrade LAA occlusion to class 1A.[18] Nevertheless, it is very important to use an LAA closure technique with proven efficacy and durability. Here, our study adds new insights, which can be implemented in clinical practice.

LIMITATIONS

This is a retrospective, nonrandomized study with its known limitations. However, our study strikingly shows the benefits of LAA clipping and surgical LAA excision, and therefore a randomized trial comparing those 2 superior techniques with other inferior techniques might not be justified. Another limitation is that it is unclear what size of the stump length is dangerous for the patients and leads to a greater risk of stroke. We chose greater than 10 mm because it has been published before and from a clinical point of view this is the most reasonable cut-off. However, this is still controversial and needs further research. In addition, the surgeons' preferences for different LAA closure techniques in this study might have influenced the results. Furthermore, we do not have serial TEE measurements and cannot provide clear data on the timing of failure in all patients.

CONCLUSIONS

In conclusion, this study provides valuable insights into comparing the efficacy of different LAA closure techniques using TEE. The study underlines the need for careful selection of LAA closure methods and suggests that LAA clipping and surgical LAA excision have proven to be the most effective techniques. External LAA ligation and stapler resection should be avoided in order to improve the patient outcome.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: left atrial appendage closure, atrial fibrillation therapy, stroke prevention