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Review Article

Surgical closure of the left atrial appendage during cardiac surgery: a review article

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ABSTRACT

The surgical occlusion of the left atrial appendage during cardiac surgery has been shown to significantly reduce the risk of stroke and systemic embolism in patients with atrial fibrillation, and it is currently a highly recommended procedure. As cardiovascular surgeons, we have the opportunity to offer this impactful additional surgical intervention, but we must be well-versed in its anatomical and surgical principles, as well as the robust evidence supporting its indication.

Keywords: Left Atrial Appendage Closure; Cardiac Surgery; Atrial Fibrillation (Source: MeSH-NLM).

RESUMEN

Cierre quirúrgico de la orejuela izquierda durante la cirugía cardiaca: artículo de revisión

La oclusión quirúrgica de la orejuela izquierda durante la cirugía cardiaca ha demostrado disminuir el riesgo de *stroke* y embolia sistémica de forma significativa en los pacientes con fibrilación auricular, siendo actualmente un procedimiento con un alto grado de recomendación. Como cirujanos cardiovasculares tenemos la oportunidad de ofrecer este procedimiento quirúrgico adicional de impacto, pero debemos conocer sus principios anatómicos y quirúrgicos, además de la mayor evidencia que sustenta su indicación.

Palabras clave: Cierre del Apéndice Auricular Izquierdo; Cirugía Cardiaca; Fibrilación Auricular (Fuente: DeCS-BIREME).

Introduction

The left atrial appendage (LAA) is the primary source of cardiac-origin emboli in patients with atrial fibrillation (AF), particularly in those with risk factors such as heart failure, hypertension, and advanced age [(1)]. During cardiac surgery, the concomitant closure of the LAA in patients with AF has been shown to significantly reduce morbidity associated with embolic events over time [(2)]. This article aims to review the anatomical and surgical foundations of LAA closure during cardiac surgery and the most relevant evidence on this subject.

Anatomy

The LAA is an appendicular extension of the left atrium [(3)] and represents the only remnant of the primitive atrium [(4)]. It originates from the lateral atrial portion, parallel to the left pulmonary veins. It predominantly extends anteriorly, curving to come into contact with various cardiac structures, including the free border of the left ventricle (LV), the right ventricular outflow tract (RVOT), and the pulmonary artery (PA) [(3)]. Structurally, it consists of three anatomical regions [(5)]: the ostium, neck, and body **(Figure 1)**. The ostium has an elliptical shape with poorly defined borders, except in its posterosuperior portion, where it becomes prominent and separates it from the orifice of the left superior pulmonary vein (left lateral ridge). The neck, with variable extension, is a particularly smooth region surrounded epicardially by Bachmann's conduction fibers [(3)]. The body is a trabeculated and multilobed area that gives the LAA its characteristic shape [(6)]. Four morphotypes of the LAA can be identified [(7)] **(Figure 2)**: "chicken wing", "windsock," "cactus," and "cauliflower". The "cauliflower" type has been associated with a higher proportion of cardioembolic events and greater surgical closure difficulty.

Externally at its base, the LAA is laterally crossed by the ligament of Marshall (or a remnant of the left superior vena cava), which separates it from the left superior pulmonary vein and serves as an important epicardial anatomical landmark **(Figure 3)**. This structure is reflected endocardially in the area of the left lateral ridge. Similarly, in the anterior-most portion of its base, the LAA is near the circumflex artery and the great cardiac vein (at the level of the atrioventricular groove), which are covered by the LAA as they pass toward the right ventricle. The thickness of its wall is generally around 1 mm, except in areas with trabecular ridges, which make the wall partially more prominent. Additional features compiled by Naksuk *et al.* [(3)] are shown in **Table 1**.

Surgical techniques for left atrial appendage closure (Central figure)

Historically, various surgical techniques have been employed for the closure of the LAA. However, only three have consistently demonstrated adequate efficacy and are widely recognized today [(8)]. These are outlined below:

- **Amputation and suture** [(8-10)]. This method, which can be performed manually or using automated sutures, is highly regarded for its safety and efficacy. In manual closure, the LAA body is excised, ensuring sufficient distance from the circumflex artery and leaving an appropriate margin of tissue for suturing. This step also facilitates inspection for thrombi within the LAA and atrium. Following this, two suture lines are applied to ensure

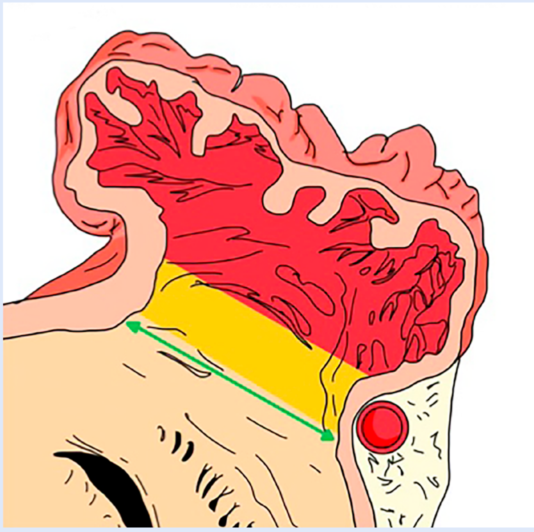


Figure 1. Anatomical regions of the left atrial appendage.

The ostium of the left atrial appendage is indicated by the bidirectional green arrow, the smooth neck of the appendage is highlighted in yellow, and the body, showing multiple trabeculations, is marked in red.

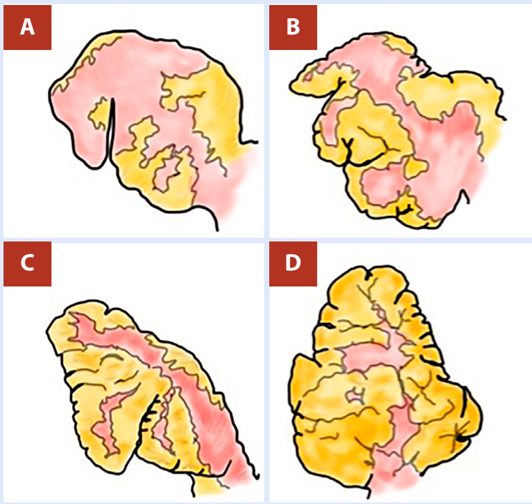


Figure 2. Morphotypes of the left atrial appendage.

A: Chicken Wing; **B:** Windsock; **C:** Cauliflower; **D:** Cactus.

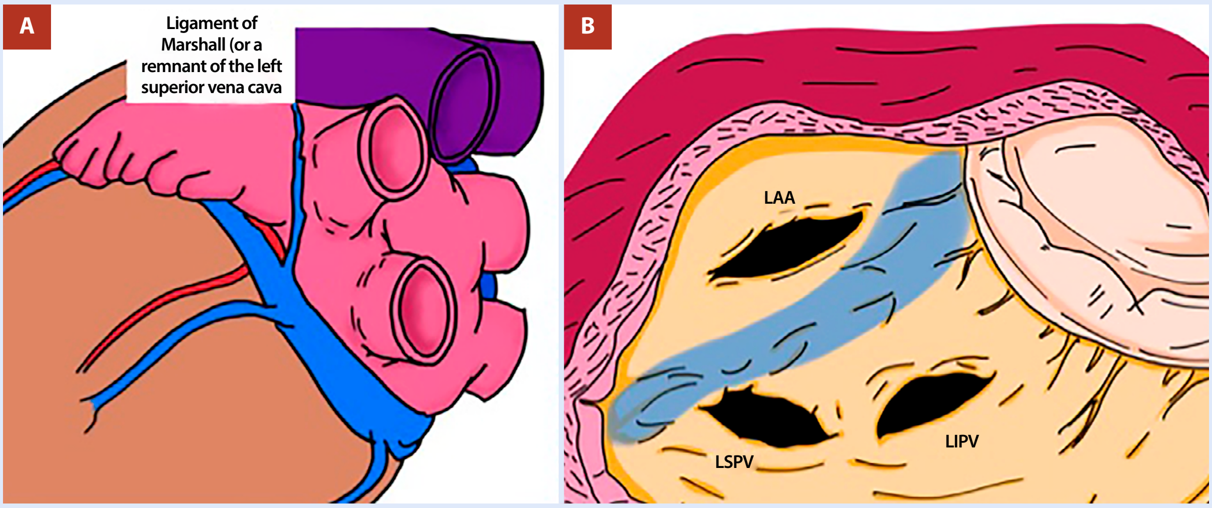


Figure 3. Anatomical landmarks related to the left atrial appendage

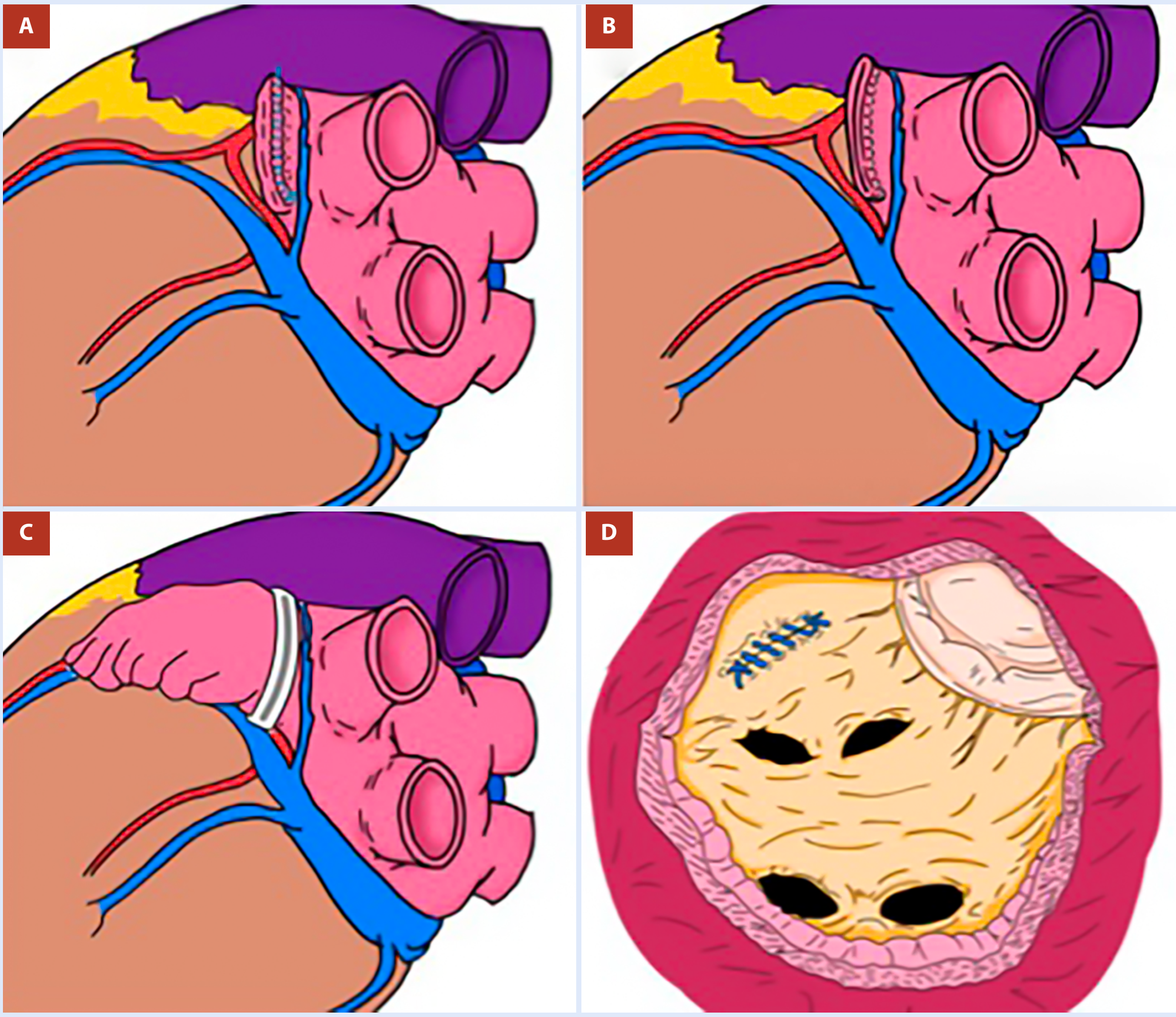
A: The relationship between the ligament of Marshall (or a remnant of the left superior vena cava) and the base of the left atrial appendage. **B:** The left lateral ridge, shown in blue, represents an internal projection of the ligament of Marshall. **LAA:** left atrial appendage; **LSPV:** left superior pulmonary vein; **LIPV:** left inferior pulmonary vein.

adequate hemostasis. The primary limitation of this technique is the potential for residual tissue, which may remain thrombogenic if exceeding 10 mm. Extra caution is necessary when dealing with "cauliflower" morphology LAAs due to their multilobed structure, which increases the likelihood of residual tissue. Other potential complications include bleeding at the suture site or, albeit rarely, injury to the circumflex artery. In the LAAOS III study, manual closure was the most commonly employed technique (55.7% of

Table 1. Morphological characteristics of the left atrial appendage

Morphology	Cactus (30%): features a central lobe with secondary lobes extending from it. Chicken Wing (48%): bends over itself after the ostium, either in the proximal or middle portion. Windsock (19%): contains a long main lobe with smaller lobes emerging within the primary lobe. Cauliflower (3%): lacks a dominant lobe and exhibits irregular morphology.
Lobes	Single lobe: 20%–70%; two lobes: 16%–54%; up to four lobes in the remaining percentage.
Ostium location	Orientation varies relative to the LSPV. In 60%–65% of individuals, it is at the same level as the LSPV; in 25%–30%, it is superior. The remaining percentage has an inferior position.
Ostium shape	Elliptical (69%), circular, triangular, teardrop-shaped, or foot-like.
Ostium width	21.9 ± 4.1 mm
Ostium length	49.4 ± 9.1 mm
Ostium depth	16–51 mm
Pits	Various pits may surround the ostium, potentially contributing to thrombus formation. These pits typically measure between 0.5 and 10.3 mm.
Body	The LAA features a narrow base with a hook-shaped apex pointing inferiorly. A wide body with a narrow neck is characteristic.
Curvature	The LAA follows a curved course, bending at 90° ± 20° after the first 14 ± 4 mm (75%).
Tip direction	Predominantly follows an anterior and cranial trajectory, covering the pulmonary artery trunk, though it can extend in other directions.
Wall thickness	Approximately 1 mm (range: 0.4–1.5 mm).

LSPV: left superior pulmonary vein. LAA: left atrial appendage. PA: pulmonary artery.



Central figure. Surgical techniques for left atrial appendage closure.

A: Closure by excision and suturing; **B:** Closure with automated suturing; **C:** Closure with an epicardial clip; **D:** Endoatrial closure.

cases). Automated suturing devices, while a promising alternative, require a high level of operator familiarity and experience to achieve optimal results [9].

- **Endoatrial closure.** Earlier approaches using single-plane or simple sutures were found to be largely ineffective when assessed through echocardiography [11]. The contemporary technique employs two suture planes. The first involves intussusception of the LAA body into the suture line, while the second uses a Lambert-style suture to imbricate the lateral walls of the left atrium [8]. This method has demonstrated satisfactory success rates and is particularly valuable in minimally invasive mitral valve surgery. The main drawback lies in the potential for residual flow into the LAA if the technique is improperly executed, which may increase the risk of embolic events [12], a matter discussed in more detail later.

- **Epicardial clipping.** Recent advancements have introduced devices such as the AtriClip [13] and Penditure LAA [14] for epicardial treatment. These devices are relatively easy to use, making them suitable for both open and minimally invasive surgeries [15]. Given their entirely extracardiac application, anticoagulation is not required solely for their use [16]. The main obstacle in certain regions, including ours, is the high cost of these devices, with a reported price of approximately $1,800 per unit in the LAAOS III study [17]. Furthermore, regulatory hurdles for adopting new technologies may also limit their accessibility.

Criteria for adequate surgical closure

The LAAOS studies [9,10,18] established stringent echocardiographic criteria for defining adequate closure of the LAA, which have been widely adopted in both research and clinical practice. These criteria include:

- Residual stump less than 10 mm (for excision techniques): while this criterion is widely used, its adoption is somewhat arbitrary. The LAAOS study [9] used this benchmark because it represents more than half the length of the smallest LAA observed before occlusion.
- No residual flow into the LAA (for exclusion techniques): this criterion is of significant importance due to the risk of post-procedural embolism. Aryana *et al.* [12] conducted a study to assess the risk of ischemic stroke and systemic embolization in a contemporary cohort of patients undergoing surgical LAA ligation concomitant with cardiac surgery. The closure technique involved double-layer continuous over-suturing, achieving a 64% rate of complete occlusion. This study found that incomplete LAA ligation (defined by the presence of a narrow neck connecting the left atrium to an intact LAA, as evidenced by tomography) was an independent predictor of stroke or systemic embolism in both univariate (Odds Ratio [OR]: 16.6, 95% confidence interval [CI]: 1.7-161.4, p = 0.015) and multivariate analyses (OR: 20, 95% CI: 1.92–212.68, p = 0.012). Notably, the annual risk of these outcomes per 100 patient-years was higher with smaller residual neck diameters (19% for a neck diameter < 5 mm).

Analysis of evidence

Randomised studies

These studies provide the strongest evidence supporting LAA closure during cardiac surgery. Their key characteristics and findings are summarized below:

LAAOS [9] (2005): this was a single-center pilot randomized study aimed at assessing the safety and efficacy of LAA closure during coronary surgery in adult patients with AF who also had at least one stroke risk factor. Transesophageal echocardiographic evaluation was conducted 8 weeks postoperatively to assess occlusion rates, using previously described failure criteria. Initially, the closure technique involved a purse-string or single-layer continuous suture in the first 16 cases. However, due to low occlusion rates, the method was replaced with automated sutures. Among the 52 patients in the intervention group, effective occlusion was achieved in 66% of cases. Importantly, no significant differences were observed in safety endpoints, including cardiopulmonary bypass time, postoperative bleeding, or thromboembolic events.

LAAOS II [18] (2013): this multicenter study comprised two pilot investigations:

(a) Cross-sectional study: it was performed to determine the prevalence of AF in adults undergoing cardiac surgery at four centers. Of the 1,889 patients recruited over seven months, 204 (10.8%) had AF. These patients were evaluated for potential inclusion in the subsequent trial.

(b) Pilot trial: the study aimed to evaluate the feasibility of recruiting patients for a larger randomized trial comparing LAA occlusion with no occlusion. A total of 51 patients were enrolled, with 26 allocated to the occlusion group. Recruitment exceeded expectations, achieving an average rate of 3.2 patients per month, surpassing the target of two patients per month. Effective LAA occlusion was achieved in all cases, adding only 10 minutes to the overall surgical time, with no reported bleeding at the closure site.

LAAOS III [2] (2021): a randomized, double-blind, multicenter study conducted in adult patients undergoing cardiac surgery with cardiopulmonary bypass who had a CHA2DS2-VASc score of at least two. The study compared whether LAA occlusion (via amputation and closure, automated sutures, two-layer linear closure, or epicardial clipping) versus no occlusion, in addition to routine care (including anticoagulation in both groups), could prevent the composite outcome of ischemic stroke or systemic embolism. A total of 4,811 patients were recruited over nearly nine years before the trial was halted for safety reasons. Intention-to-treat analysis revealed that ischemic stroke or systemic embolism occurred in 4.8% of the occlusion group compared to 7.0% in the control group (Hazard Ratio [HR]: 0.67; 95% CI: 0.53-0.85; p = 0.001), indicating a 33% reduction in the primary outcome. This benefit became statistically significant 30 days post-intervention, as shown in the time-to-event curve. The authors calculated the number needed to treat (NNT) of 37 patients (95% CI: 22-111) to prevent one stroke over a five-year period.

A notable aspect of this study was the strict adherence to ensuring adequate LAA closure, with no incomplete closure permitted in the intervention group. A subsequent analysis by Connolly *et al.* [19] examined whether the stroke risk reduction from LAA closure varied based on anticoagulation therapy. The findings showed that the benefit was independent of the type of anticoagulation used, whether vitamin K antagonists, direct oral anticoagulants, or no anticoagulation. In 2023, Eqbal *et al.* [17] conducted an economic evaluation of LAA closure in the LAAOS III study. They reported a reduction in costs favoring the occlusion group ($3,878 vs. $4,490; mean difference: -$612, 95% CI: -$1,276 to -$45), primarily due to reduced stroke-related care costs. This cost-saving effect was most pronounced beyond 30 days post-surgery and was consistent across subgroup analyses.

LAACS study [20] (2022): the LAACS study was a randomized, open-label trial with a blinded outcome assessment, designed to evaluate the effect of routine LAA closure during the first cardiac surgery in patients with and without AF. Patients scheduled for planned LAA closure, ablation, or off-pump surgery were excluded. The recommended closure technique was two-layer suturing, which was performed in 95% of cases. Following LAA closure, patients had no restrictions regarding contemporary general treatment. The primary outcome was a composite of clinical stroke events. Data from 186 patients (82% male) were analyzed, with 13.4% having AF and 25.9% receiving oral anticoagulation. Over a median follow-up of 6.2 years, intention-to-treat analysis showed that 21% of patients in the control group experienced the primary outcome compared to 11% in the intervention group. The cumulative incidence curve was significantly lower in the intervention group than in the control group (p = 0.033). The authors concluded that LAA closure may offer potential benefits in reducing cerebrovascular events over time, regardless of preoperative AF status. The ongoing LAACS-2 study [21], a multicenter protocol involving hospitals from three countries, aims to provide more robust evidence to validate this hypothesis.

Key observational studies

Friedman *et al.* [22] (2018) conducted a retrospective cohort study involving 10,524 patients who underwent cardiac surgery and had AF. The primary outcome was readmission due to thromboembolism during a three-year follow-up. Secondary outcomes included hemorrhagic stroke incidence, all-cause mortality, and a composite of the primary and secondary outcomes. The study found that only 37% (n = 3,892) of patients underwent LAA occlusion. Surgical LAA closure was associated with significantly lower unadjusted rates of thromboembolism (4.2% vs. 6.2%; subdistribution HR [sHR]: 0.66; 95% CI: 0.56-0.79; p < 0.001), all-cause mortality (17.3% vs. 23.9%; HR: 0.70; 95% CI: 0.64-0.77; p < 0.001), and the composite outcome (20.5% vs. 28.7%; HR: 0.69; 95% CI: 0.63-0.75; p < 0.001). No significant differences were observed in hemorrhagic stroke incidence (0.9% vs. 0.9%). These associations remained robust after adjustment.

Petersen *et al.* [11] (2024) conducted a retrospective study analyzing 149 patients with AF who underwent cardiac surgery. Using transesophageal echocardiography, the study evaluated the efficacy of four surgical LAA closure techniques: atrial clipping, suturing and external ligation, resection with automated sutures, and amputation with suturing. The results showed high closure success rates for atrial clipping (98.4%) and surgical resection (93.1%). Patients undergoing coronary artery bypass grafting had the highest failure rates for LAA closure.

Systematic reviews

The meta-analysis with the largest number of patients was conducted by Mohamed *et al.* [23] in 2021, which included data from five randomized studies. A total of 2,580 patients with AF who underwent surgical LAA closure during cardiac surgery were compared to 2,548 controls. The primary outcome was the occurrence of long-term thromboembolic events (stroke, transient ischemic attack [TIA], or systemic embolism). The mean follow-up duration was 3.7 years, the mean age of participants was 71 years, and the mean CHA2DS2-VASc score was 4.1 ± 1.5. The study showed that patients in the closure group had significantly lower rates of the primary outcome compared to the control group (Rate Ratio [RR]: 0.67; 95% CI: 0.53-0.84; p < 0.01). Secondary outcomes, including all-cause mortality, major bleeding/transfusion, and myocardial infarction, were not significantly different between groups.

Clinical practice guidelines

In recent years, driven by the evidence provided by the LAAOS III study, the recommendation level for LAA closure in AF guidelines from various medical societies has been elevated.

- ACC/AHA guidelines (2023) [24]: the recommendation level for LAA closure in patients with AF (CHA2DS2-VASc score > 2 or equivalent stroke risk) undergoing cardiac surgery, in addition to continued anticoagulation, to reduce the risk of stroke and systemic embolism, was upgraded from IIb (Level B-NR) to I (Level A). Similarly, the use of surgical techniques ensuring proper LAA closure now has a Class I (Level A) recommendation. However, the guidelines also state that the discontinuation of anticoagulation therapy after LAA closure remains uncertain (Class IIb, Level A).
- STS atrial fibrillation guidelines (2023) [25]: the STS guidelines recommend concomitant LAA closure for patients undergoing their first non-emergency cardiac surgery, with or without concomitant surgical ablation, to reduce morbidity associated with thromboembolic complications. This recommendation is rated Class I (Level A).
- ESC/EACTS guidelines (2024) [26]: similar to the American guidelines, the ESC/EACTS guidelines increased the recommendation for LAA obliteration during cardiac surgery from IIb (Level C) in the previous edition to I (Level B).

Conclusion

The current evidence strongly supports the concomitant closure of the LAA during cardiac surgery in patients with AF. This procedure is both safe and effective when performed by surgeons with adequate surgical expertise. To achieve optimal outcomes, cardiac surgeons must be well-versed in the anatomical, physiological, and technical principles that underpin a successful procedure. The criteria for adequate LAA closure have enabled the standardization of high-quality procedures, making it imperative to extend their application to as many patients as possible. The significant reduction in morbidity associated with stroke achieved through this intervention underscores its critical role in improving patient outcomes.

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