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EMBOLIZATION OF PERCUTANEOUS LEFT ATRIAL APPENDAGE CLOSURE DEVICES: TIMING, MANAGEMENT AND CLINICAL OUTCOMES

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ABBREVIATIONS: AF, atrial fibrillation; LAA, left atrial appendage; LAAC, left atrial appendage closure; BARC, bleeding Academic Research Consortium; CT, computed tomography; DAPT, dual antiplatelet therapy; DOAC, direct oral anticoagulation; ICE, intracardiac echocardiography; LV, left ventricle; SAPT, single antiplatelet therapy; TEE, transesophageal echocardiography; TIA, transient ischemic attack.

KEYWORDS:

Left atrial appendage closure

Device embolization

Atrial fibrillation

Occluder embolization

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Retrieval strategy

Stroke prevention

ABSTRACT

Background: Left atrial appendage (LAA) occluder embolization is an infrequent but serious complication.

Objectives: We aim to describe timing, management and clinical outcomes of device embolization in a multi-center registry. Methods: Patient characteristics, imaging findings and procedure and follow-up data were collected retrospectively. Device embolizations were categorized according to 1) timing 2) management and 3) clinical outcomes.

Results: Sixty-seven centers contributed data. Device embolization occurred in 108 patients. In 70.4 % of cases, it happened within the first 24 h of the procedure. The device was purposefully left in the LA and the aorta in two (1.9 %) patients, an initial percutaneous retrieval was attempted in 81 (75.0 %) and surgery without prior percutaneous retrieval attempt was performed in 23 (21.3 %) patients. Two patients died before a retrieval attempt could be made. In 28/81 (34.6 %) patients with an initial percutaneous retrieval attempt a second, additional attempt was performed, which was associated with a high mortality (death in patients with one attempt: 2.9 % vs. second attempt: 21.4 %, $p < 0.001$). The primary outcome (bailout surgery, cardiogenic shock, stroke, TIA, and/or death) occurred in 47 (43.5 %) patients. Other major complications related to device embolization occurred in 21 (19.4 %) patients.

Conclusions: The majority of device embolizations after LAA closure occurs early. A percutaneous approach is often the preferred method for a first rescue attempt. Major adverse event rates, including death, are high particularly if the first retrieval attempt was unsuccessful.

Condensed abstract: This dedicated multicenter registry examined timing, management, and clinical outcome of device embolization. Early embolization (70.4 %) was most frequent. As a first rescue attempt, percutaneous retrieval was preferred in 75.0 %, followed by surgical removal (21.3 %). In patients with a second retrieval attempt a higher mortality (death first attempt: 2.9 %vs. death second attempt: 24.1 %, $p < 0.001$) was observed. Mortality (10.2 %) and the major complication rate after device embolization were high.

1. Introduction

Percutaneous left atrial appendage closure (LAAC) has been shown to be non-inferior to Vitamin K antagonists in preventing stroke in patients with AF [1–5]. However, despite the established safety profile of LAAC, serious complications such as device embolization can occur.

Current studies report device embolization rates between 0 and 3.9 % per 100 person-years [6]. To date, the evidence available about this topic is limited to case reports [7–12], a case series [13], a

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systematic review [14] and a larger literature review of 103 cases [15]. This study is the first large-scale registry examining timing, management and clinical outcomes of LAAC device embolization.

2. Methods

This is an international, multicenter registry of consecutive patients with device embolization. Embolizations occurred between 03/2004 and 07/2021 and were identified in prospectively maintained databases approved by each local Institutional Review Board. Patient characteristics, imaging findings, procedure and follow-up data were collected retrospectively from medical records and entered into a standardized electronic case report form evaluated centrally. The device choice, implanting technique, and embolization management strategy were at the discretion of the implanting physician and depended on anatomical factors, operators' experience and available equipment.

Device embolizations were analyzed focusing on 1) timing (i.e., intraprocedural [within the first 24 h after implantation], early [after 24 h but within 45 days] and late [>45 days after implantation]) 2) management (conservative management, percutaneous retrieval, or surgery) and 3) clinical outcomes.

Management strategies were divided into first and a second retrieval attempt and conservative management. The first retrieval attempt included 1) percutaneous retrieval or 2) surgery.

The combined primary outcome of this study was a composite of bailout surgery, cardiogenic shock, stroke/TIA and death. Secondary outcomes included other major complications.

2.1. STATISTICAL ANALYSIS

Incidences are expressed as percentages. Continuous variables with normal distribution are presented as mean with standard deviation and nonparametric variables reported as median with interquartile ranges (25th to 75th). The Kolmogorov-Smirnov test was used to test for normal distribution. Independent groups were compared with Student's t-test, the Mann- Whitney-U test as or Chi-Square test as appropriate. A p-value ≤ 0.05 was considered statistically significant. IBM SPSS Statistics (Version 28.0.1.0, IBM Germany GmbH, Ehningen, Germany) was used for statistical analysis and Prism 9 (GraphPad Software, San Diego, CA, USA) for graphing.

2.2. ETHICAL CONSIDERATIONS

The study is in line with the Declaration of Helsinki and was approved by the local ethics committee (Landesärztekammer Hessen, No. 2021- 2432-evBO). The study is registered at ClinicalTrials.gov (NCT05014477).

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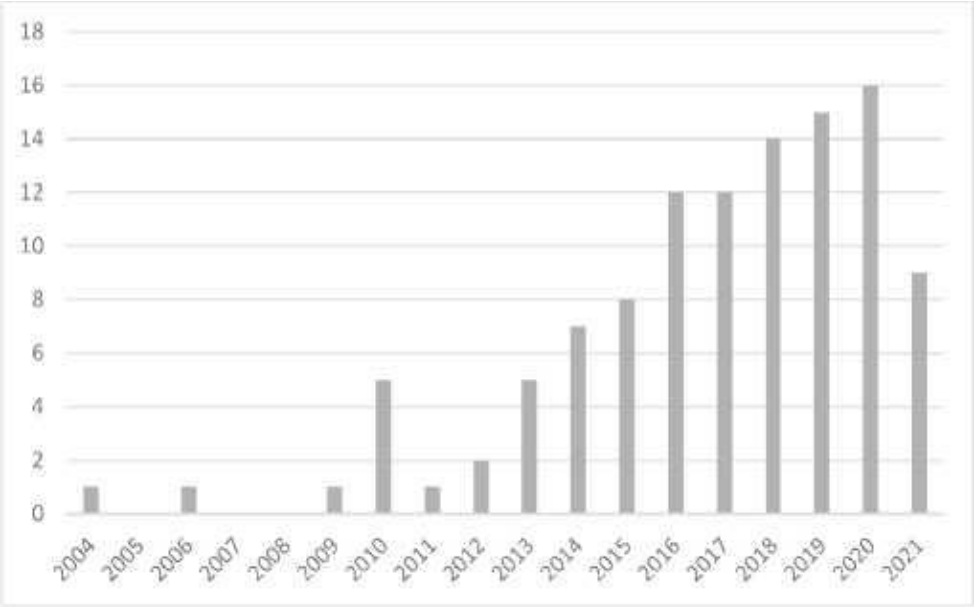
3. Results

Sixty-seven centers provided data on 125 patients who experienced left atrial appendage (LAA) device embolization between 03/2004 and 07/ 2021. Fig. 1 outlines the number of device embolizations reported for the respective years. However, the total number of LAAC for the respective years is not available. Hence, the increasing number of device embolizations over the years may be a result of an increasing number of LAAC performed rather than an increase in embolization rates. Centers that implanted more than the median of 241 patients (IQR: 132 – 313) between 03/2004 and 07/2021 were classified as high-volume centers. During this time period, high volume centers described an embolization rate of 0.6 % versus 1.5 % in low-volume centers.

Fig. 1. *Amount of recorded LAA closure device embolizations per year.*



Please note, not all centers provided the total number of LAA closures. In centers that did report the overall number of LAA closures, the total number of closures were 12,903 and the number of embolizations were 78 (0.6 %). Seventeen cases did not meet the inclusion criteria of this study and were excluded from analysis because the devices were still in the LAA with a peri-device leak or dislocated partially without embolization. Two other patients died before any rescue attempt could be undertaken: one had multiple strokes half a year after LAAC. Imaging showed massive thrombus formation in the left atrium (LA) and on the device which was located within the LA. Before heart surgery could be performed, the patient had further strokes and ultimately died of intracranial hemorrhage. Another patient experienced a seizure 1.5 years after device implantation. The device was in the infrarenal abdominal aorta. Because of the general status of the patient, only the seizure but not the device migration was treated. The patient died shortly thereafter. Conservative management was chosen for two patients with devices left in the LA and aorta compromising flow into the coeliac trunk. All (n = 104) other patients underwent an attempt of device retrieval.

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3.1. BASELINE CHARACTERISTICS

Average age was 74 ± 9 years in a male predominant cohort (n = 78, 72.2 %). Patients had a mean CHA2DS2-VASc score of 4.4 ± 1.3 and a mean HASBLED score of 3.3 ± 1. Chronic kidney disease (estimated glo¬merular filtration rate ≤ 60 mL/min) was present in 48 (44.4 %) patients, five (4.6 %) patients were on chronic renal replacement therapy. Forty pa¬tients (37.0 %) had a stroke history. The etiology of prior strokes (e.g. whether or not it was related to atrial fibrillation or other causes) was not reported. Further baseline characteristics are shown in Table 1.

3.2. PROCEDURAL CHARACTERISTICS

The most common reason for percutaneous LAAC was prior bleeding (64.8 %), especially intracranial hemorrhage (39.0 %). Further indications were a high bleeding risk without previous bleeding (10.2 %), patient preference (6.5 %), strokes while on OAC (4.6 %), anemia (1.9 %), and others (18.5 %).

The majority of embolized devices were Amplatzer Amulet™ occluders (Abbott, Minneapolis, MN, USA; n = 47, 43.5 %), followed by first- generation Watchman™ devices (Boston Scientific, Marlborough, MA, USA, n = 25, 23.1 %). Table 2 provides an overview of embolized devices. General anesthesia was chosen over conscious sedation in most cases (70.3 %). The mean device size was 26.6 ± 3.6 mm (Amulet/ACP: 26.6 mm; Watchman: 26.4 mm) similar to earlier findings where occluders of 27 mm were used most commonly [16]. Of all devices that embolized into the ventricle, the mean device size was 27.1 mm, while the average de¬vice size of those that embolized into the aorta was 24.8 mm. Procedure duration was 96.9 ± 65.3 min, contrast volume 110 ± 69 mL and fluoroscopy time 24.4 ± 17.2 min. In the reporting of participating centers it was not clarified if this included the time of the initial LACC procedure or not. Hence, particularly in cases in which embolizations were recognized before completion of the LAAC procedure, the index procedure time and retrieval procedure time may have been included in the reporting. Further information on LAA dimensions and anatomy is shown in Table 3.

3.3. SYMPTOMS OF DEVICE EMBOLIZATION

Most patients were asymptomatic when device embolization was detected (76.8 %). Intraprocedurally, hemodynamic instability occurred in 2.8 % (n = 3), acute pulmonary edema in 2.8 % (n = 3), ventricular tachycardia in 3.7 % (n = 4) and acute severe mitral regurgitation in 13.0 % (n = 14). Some patients (18.5 %; n = 20) had cardiovascular symptoms including drowsiness, dyspnea and extrasystoles. Others presented with neurological and other symptoms including vertigo, visual impairment, photopsia, disorientation, paraphasia, tremor or leg claudication and abdominal pain (9.3 %; n = 10).

3.4. DEVICE EMBOLIZATION CHARACTERISTICS

3.4.1. TIMING AND DEVICE LOCATION

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The majority of device embolizations occurred within 24 h after implantation (70.4 % vs. 29.6 %; p < 0.001) with most (45.3 %) detected intraprocedurally. Later embolizations (>45 days) accounted for 19.4 % of cases. Major complications occurred in 65.3 % (32/49) if the device embolized intraprocedurally and in 53.3 % (32/60) when it was found to have embolized later.

The aorta was the most common site of device migration (37 %), followed by the left ventricle (33.6 %), the left atrium (24.3 %), and peripheral arteries (4.6 %) (Fig. 2).

3.4.2. MANAGEMENT STRATEGIES

Fig. 3 illustrates management strategies after device embolization and associated major complications. As previously discussed, two patients whose devices embolized >24 h post-procedure died before any rescue attempt was possible: one patient in the late embolization group died of a seizure and stroke >1.5 years after LAAC. However, the exact timing of the device embolization cannot be determined because the patient did not attend any follow-up appointments after his initial hospital stay. The device was located in the infrarenal abdominal aorta prior to the patient's death. The second patient died of cerebral hemorrhage after multiples strokes six months after LAAC. The device was found in the LA. Multiple thrombi were reported in the LAA and LA. A deliberate conservative approach was chosen in two (1.9 %) patients. The embolized device was found in the LA in one patient (not free floating), and in the peripheral arteries in the other without hemodynamic or clinical impact. Percutaneous rescue attempts were undertaken in 75.0 % (n = 81). Trans-arterial, retrograde retrieval was initially favored in 54.3 % (n = 44) of cases and trans-septal retrieval from the left atrium or the left ventricle in 42.0 % (n = 34) patients. In a minority (n = 4; 4.9 %), both techniques were tried. During the first percutaneous retrieval attempt, a single loop snare was most commonly used (n = 48/81, 59.2 %, immediate success rate: 68.8 %), followed by endomyocardial bioptomes (n = 11/81, 13.6 %, immediate success rate: 63.6 %) and three loop snares (n = 3/81, 3.7 %, immediate success rate: 100 %). A double snare technique was used in three patients (3.7 %, immediate success rate: 100 %). Twelve operators used a combined approach during catheter-based retrievals (14.8 %, immediate success rate: 75 %). In four cases, the device was not specified (5.0 %). In the group of percutaneously treated patients, mitral regurgitation caused by device dislocation was the most common complication (n = 8; 9.9 %), followed by cardiogenic shock (n = 7, 8.6 %) and aortic/left ventricular outflow tract obstructions (n = 6; 7.4 %).

Open heart surgery as the primary rescue approach was performed in 21.7 % of cases (n = 23/106). In 14/23 (60.9 %), the device was found in the left ventricle. Surgery after failed percutaneous attempt was performed in 16 Patients, most often on the same day (n = 14; 60.9 %) and at the same center (n = 20; 87.0 %) as the initial procedure. Reasons for heart surgery included the repair of damaged cardiac and surrounding structures which could not be managed percutaneously, such as mitral or aortic valve apparatus injuries or the need for ventricular patch-plasty. In two cases, the implanting team opted for a surgical approach because they did not have any experience with percutaneous retrieval techniques. Both patients did not experience any major complications. Not all centers provided reasons for surgical retrieval without prior percutaneous attempt. Some cited device size limitations or concerns of entanglement in the mitral valve apparatus while others mentioned concerns of aortic valve injury or LVOT obstruction and/or the possibility of performing

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simultaneous surgical LAA closure as reasons for a primary surgical approach. In centers that reported the total number of LAAC procedure performed and could,hence, be classified into low- or high-volume centers (see above), the success rate of device retrieval during the first attempt was 49 % and 55 % for low and high-volume centers respectively (p = 0.28).

In 34.6 % (28/81), a second rescue attempt was made after a first unsuccessful percutaneous attempt. In twelve cases, another percutaneous approach was chosen, primarily using single loop snares (n = 6, 50.0 %), followed by endomyocardial bioptomes (n = 2, 16.7 %), a double snare loop (n = 1, 8.3 %) and one combined approach (n = 1, 8.3 %). In one case, the device was not specified (8.3 %). One physician used a single loop snare to capture the device and firmly locked it against the catheter tip. A catcher device was advanced to grab parts of the umbrella within its forceps and retrieve the stretched device into the guiding catheter. In another case, the device was hooked with the Lasso and Catcher system simultaneously and retracted back into the sheath.

Sixteen patients underwent salvage surgery, including bailout open heart surgery in five cases where the devices were located in the left ventricle (n = 3) or LA (n = 2). Other vascular surgery (i.e., surgical repair of peripheral arteries after percutaneous rescue or surgical device retrieval) was performed in the remaining eleven patients. The need of a second retrieval attempt, especially in case of salvage surgery, was associated with increased mortality (death first attempt: 2.9 %vs. second attempt: 21.4 %,p < 0.001).

3.4.3. DEATH POTENTIALLY OR DEFINITELY RELATED TO LAA DEVICE EMBOLIZATION

Eleven patients died likely or definitely related to device embolization (10.2 %). In eight of these cases (72.7 %), the occluders embolized intra- procedurally or within 24 h (seven of these were in the ventricle [87.5 %] and one in the aorta [12.5 %]). One device was found to have embolized two weeks after the procedure and was located in the aorta at the level of the coeliac trunk (9.0 %). The remaining two were found to have embolized several months later, one dislocated into the left atrium, the other into the abdominal aorta (9.0 %, respectively).

One patient died due to acute mitral regurgitation caused by papillary muscle rupture during device retrieval in the left ventricle, following hemodynamic instability and unsuccessful resuscitation. In another patient, the device embolized into the mitral apparatus first, causing hypotension. During percutaneous retrieval, the occluder migrated into the LVOT and the patient died intraprocedurally. A third patient had a cardiac arrest with unsuccessful resuscitation during percutaneous retrieval attempt. In another case, embolization into the aorta at the coeliac trunk led to lethal abdominal and bowel ischemia. One patient died from pericardial tamponade and device migration into the left ventricle, causing severe hemodynamic instability. One patient experienced multi-organ failure after cardiac surgery performed for device retrieval from the left ventricle. One patient experienced severe lower abdominal pain during ambulation a few hours post-procedure. The device was found in the abdominal aorta compromising flow to the renal arteries. A failed percutaneous retrieval attempt was followed by successful surgical removal. Intermittent dialysis was required, a prolonged hospital course ensued, and the patient ultimately died in-hospital.

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In one patient, the device embolized into the left ventricle (recognized 8 h after the procedure by routine echo) and could be pulled into the aorta. Further retrieval attempts from the aorta/iliac artery were unsuccessful, and the device was left in the iliac artery without affecting lower extremity circulation. The patient died five days later in-hospital due to pneumonia and sepsis. In another patient, the device embolized into the left ventricle during the implantation procedure and could be mobilized into the aorta from where it was retrieved. The patient died in-hospital 35 days after the implantation procedure from an infection and pancreatitis. One patient's device was found dislocated into the left atrium seven months post-procedure when he presented with multiple strokes. Cardiac surgery was delayed in attempt to reduce the risk of cerebral hemorrhage due to anticoagulation. However, the patient became unstable, experienced new strokes and cerebral hemorrhage, and died. One patient whose device was found to have embolized 18 months post-procedure into the abdominal aorta had a seizure. Due to generalized weakness and multiple comorbidities, a conservative approach was pursued. The patient died during hospitalization.

3.5. CLINICAL FOLLOW-UP

Median follow-up time was 60 (IQR: 30–136) days. The combined primary outcome (bailout cardiac surgery, cardiogenic shock, stroke/TIA and death) occurred in 47 patients (43.5 %). All other major complications (21 patients [19.4 %]) are shown in Table 4. The median length of inhospital stay was five (IQR: 3–11) days. Patients undergoing heart surgery had a significantly longer stay than those who were treated with a percutaneous approach only (14.9 days vs. 5.4 days, $p < 0.001$). Thirty-eight (35.2 %) patients underwent an additional percutaneous attempt to close the LAA which was not successful once. In this case, LAAC had been performed during the same procedure after the embolized device was removed.

***Table 1**. Baseline characteristics.*

Characteristic	
Average age	74 ± 9 years
CHA2DS2-VASc score	4.4 ± 1.3
HASBLED score	3.3 ± 1
Characteristic	**Number of patients (% of total)**
Sex	
- Male	78 (72.2)
- Female	30 (27.8)
Hypertension	96 (88.9)
Insulin dependent diabetes mellitus	6 (5.6)
Hyperlipidemia	66 (61.1)
Chronic renal insufficiency (eGFR ≤ 60 mL/min)	48 (44.4)
Renal replacement therapy	5 (4.6)
Chronic heart failure	34 (31.5)
Coronary heart disease	46 (42.6)
Prior transitory ischemic attack	12 (11.1)
Prior ischemic stroke	40 (37.0)
Atrial fibrillation	
- Paroxysmal	43 (39.8)
- Persistent	29 (26.9)

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- Permanent	35 (32.4)
Atrial flutter	13 (12.0)
Severe mitral regurgitation	6 (5.6)
Anticoagulation regime	
- Direct oral anticoagulant	48 (44.4)
- Vitamin-K-antagonist	24 (22.2)
- Single or dual antiplatelet therapy	39 (36.1)

Table 2. *Device details and degree of oversizing.*

Device type	
Amplatzer Amulet™ (Abbott, Minneapolis, MN, USA)	47 (43.5 %)
Watchman™ (Boston Scientific, Marlborough, MA, USA USA)	36 (33.3 %)
First generation Watchman	25 (23.1 %)
Watchman FLX	9 (8.3 %)
Atritech	2 (1.9 %)
ACP (Amplatzer Cardiac Plug, AGA, St. Jude Medical, Minneapolis, MN)	17 (15.7 %)
LAmbre	6 (5.6 %)
Occlutech	2 (1.9 %)
Average device diameter 26.6 ± 3.6 mm (Amulet/ACP: 26.6 mm; Watchman: 26.4 mm)	
Oversizing	67 (62.0 %);
Degree of oversizing	18.6 % ± 2.1 %
Undersizing	14 (13.0 %)

Table 3*. LAA dimensions and anatomy.*

LAA dimensions	
Diameter (mm)	33.9 ± 14.1
Length (mm)	27.8 ± 7.4
Landing zone (mm)	22 ± 4.6
LAA flow velocity ≤ 55 m/s	49 (45.4 %)
Anatomy	
Chicken wing	37 (34.2 %)
Windsock	32 (29.6 %)
Cauliflower	15 (13.9 %)
Cactus	10 (9.3 %)
Double lobe	6 (5.6 %)
Others	1 (0.9 %)

Fig. 2. *Timing and location of embolized LAAC devices.*

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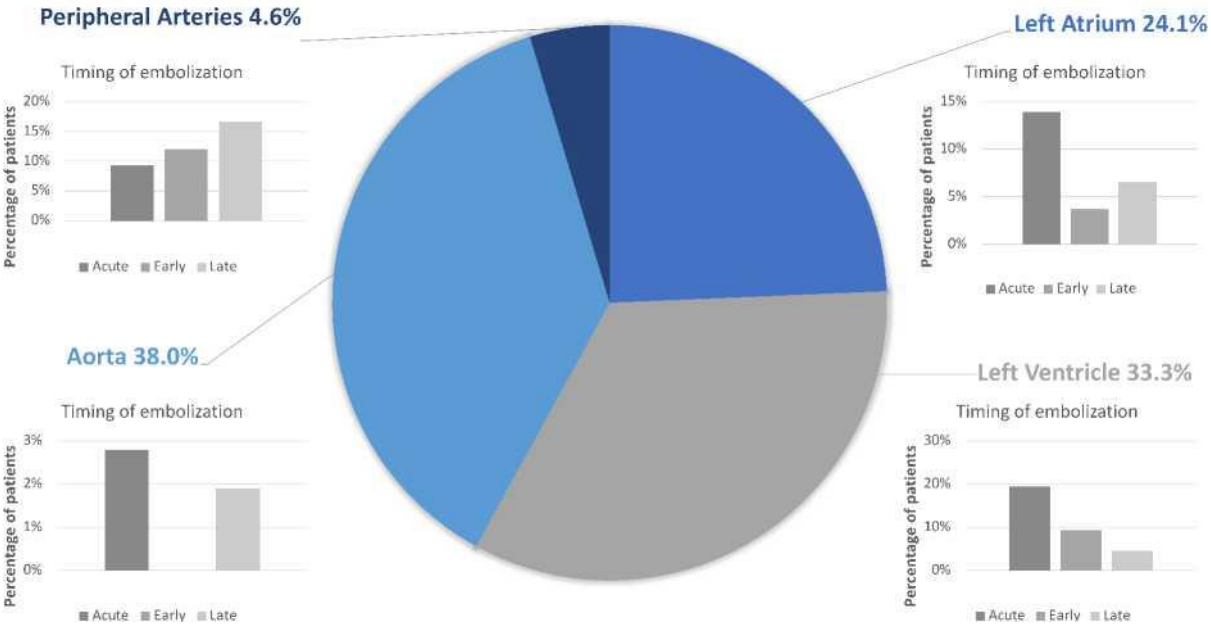
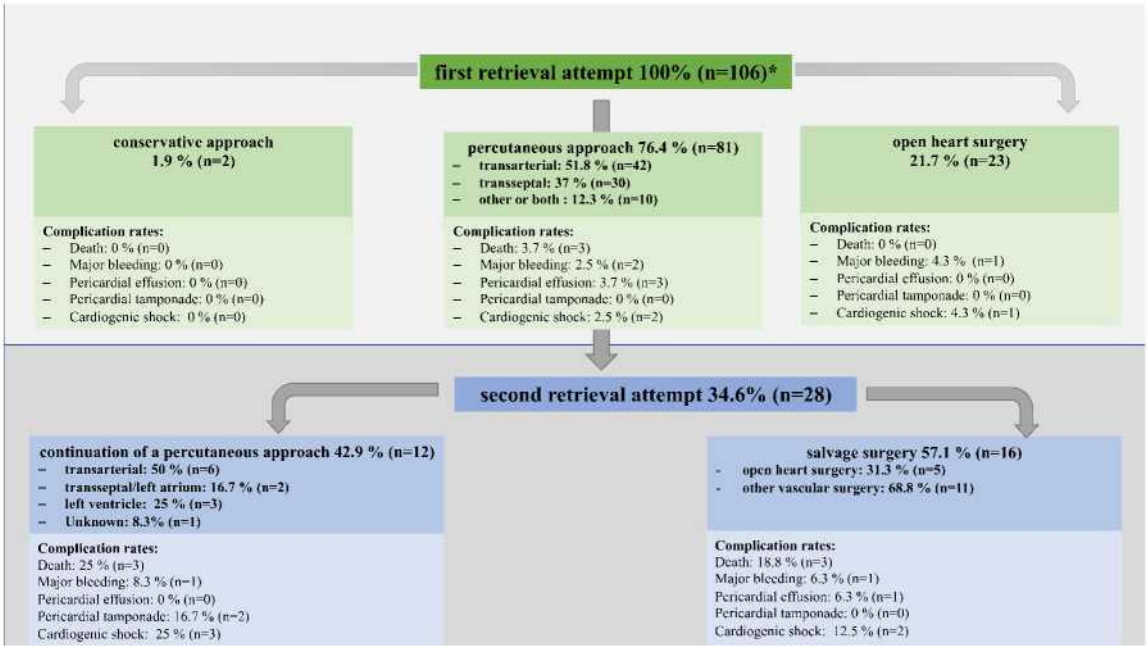


Fig. 3. *Retrieval attempts and techniques after LAAC device embolization. * Two patients died before any further intervention could be carried out which is the reason why they are not represented in this figure.*



4. Discussion

LAAC is increasingly performed in patients with atrial fibrillation. Despite over 20 years of clinical experience with catheter-based LAAC, a number of randomized controlled trials and post-market registries [5,19–22] demonstrating safety and efficacy and several device iterations and concepts,

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serious complications including device associated thrombus formation, pericardial effusion and device embolization continue to be reported regardless of the device and experience of the operators [23].

Among the aforementioned complications, device embolization has been studied and characterized least in a systematic fashion [1,2,7–15,24–30]. This is the first dedicated registry investigating timing, management strategies and associated clinical outcomes. The principal findings of the present investigation are (Central Figure):

1) Though the majority of embolization were detected within 24 h, a considerable number of embolized occluders were detected later (29.6 %).
2) A percutaneous retrieval attempt was most often chosen as the primary rescue option.
3) Approximately one third of patients required a second rescue attempt, which was associated with increased mortality.
4) Device embolization is a serious complication because it is associated with a high mortality and morbidity.

Earlier investigations did not reach full agreement regarding the timing of device embolization (i.e., acute [during the procedure] vs. subacute) [14,15]. However, most embolizations occur during the index hospitalization allowing early detection and treatment. To prevent device embolization, precautions should be taken, such as multiplanar transesophageal echocardiographic imaging and/or pre-procedural computed tomography (CT) for device sizing and occluder type selection. Apart from sizing, CT offers patient-specific computational simulations [31]. However, currently available sizing charts rely on transesophageal data. Though significant differences in the LAA device landing zone have been demonstrated after fluid administration in patients with low left atrial pressure [32] and this would appear to decrease the risk of device undersizing and perhaps embolization, the utility of this approach has not been proven [27,33]. Additionally, the usefulness of the tug test for device stability has been questioned by bench-testing [34] and clinical investigations [35], despite its recommendation by manufacturers. Certain anatomical factors may be more prone to device embolization. However, we could not detect a correlation between unusual LAA shapes and embolization in our dataset.

Once device embolization is diagnosed, individualized management is important. If the device embolization does not cause any interference with blood flow or other limitations (i.e., if the device is lodged in the aorta in a stable position without blood flow limitation to other organs) the embolized device may be left in place after individual benefit-risk-evaluation. Emergency surgery can be necessary if the device interferes with the mitral or aortic valve apparatus or causes hemodynamic instability in the LVOT. In line with other investigations [11,12,36], a percutaneous approach is most commonly employed, and training in these techniques before performing left atrial appendage might improve familiarity equipment and techniques and, consequently, success. Immediate success rates seem to be the highest with single and multiloop snares, but this conclusion has to be drawn with caution because the location of the embolized device, the patient's hemodynamic stability and operator experience play an important role.

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Second attempts at retrieval carry a higher risk of complications and mortality, likely due to more aggressive measures or challenging device locations. The rate of major complications and mortality was high and in a majority of lethal outcomes the device was located in the left ventricle. Further improvement in device technology, concepts and strategies to prevent embolization as well as development of equipment that facilitates safe and easy device retrieval are needed.

Table 4. *Clinical outcomes.*

	All attempts (n = 108 embolizations)	First retrieval attempt	Second retrieval attempt
Primary outcomes Heart surgery (=bailout + immediate surgery)	39 (36.1 %)	23 (21.3 %)	16 (14.8 %)
Cardiogenic shock	8 (7.4 %)	3 (2.8 %)	5 (4.6 %)
Death	11 (10.2 %)	3 (2.8 %)	8 (7.4 %)
Stroke	3 (2.8 %)		
Transitory ischemic attack	1 (0.9 %)	1 (0.9 %)	0 (0 %)
Secondary outcomesLeft atrial appendage perforation	2 (1.8 %)		
Pericardial effusion	4 (3.7 %)		
Pericardial tamponade	2 (1.8 %)		
Bleeding complications	11 (10.2 %)		
- Major bleeding	5 (4.6 %)		
- Minor bleeding	6 (5.6 %)		
Multiorgan failure	6 (5.6 %)		
Mitral regurgitation caused by device embolization or the retrieval attempt	17 (15.7 %)		
Device-related aortic valve injury	1 (0.9 %)		
Aortic obstruction caused by device embolization	6 (5.6 %)		
Need for renal replacement therapy	4 (3.7 %)		

4.1. LIMITATIONS

This retrospective registry uses on-site data from various centers, collected over a large time span and with different devices and device generations. The data is insufficient to allow any conclusion on the impact of the implanting team's experience on outcomes. Reporting bias may underestimate the seriousness of this complication (i.e., there may be reluctance to disclose fatal or serious consequences of device embolization). Lack of information for example on device position, compression, residual leak, shoulder and/or individual operator experience limits conclusions on the reasons for and potential avoidance of embolizations. Many patients did not undergo routine imaging follow-up shortly after device implantation. Therefore, it is conceivable that some of the late embolizations may have occurred earlier and were not detected. Importantly, it is possible that some device embolizations cause sudden cardiac death before the diagnosis could be made. This may lead to underestimation of the prevalence and the mortality associated with device em-

bolization. The rate of other complications of LAAC was not reported because it was not focus of this study but would be important to view the embolization rate in context.

5. Conclusion

Most LAAC device embolizations are diagnosed early (≤24 h) and can be managed successfully percutaneously. However, major adverse event rates including death related to this complication are high, particularly if the first retrieval attempt was not successful. More efforts should focus on prevention and management of device embolization.

6. Clinical perspectives

Percutaneous approaches to embolized LAA closure devices are often successful during the first and even the second approach. However, potentially fatal consequences during and after occluder implantation should raise awareness that, ultimately, surgery may be necessary.

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DECLARATION OF COMPETING INTEREST

A. Aminian is a consultant and proctor for Boston Scientific and Abbott. I. Akin received lecture and proctoring fees from Boston Scientific for the Watchman Okkluder. J. Lund discloses a clinical advisor (proctor) role in LAAC (Abbott) and lecture fees (Abbott, Boston scientific). E. Guerios serves

as proctor for LAA closure for Abbott and Lifetech Scientific. N. Amabile has received proctoring and consulting fees from Abbott Vascular and Boston Scientific. C. Skurk has received proctor honoraria from Boston Scientific and speaker fees from Boston Scientific and Lifetech Scientific. J. Harvey is proctor for Abiomed, Boston Scientific and Medtronic and part of the Speaker's bureau for Abiomed, Boston Scientific and Medtronic. He also is part of the advisory board for Avail, Boston Scientific and Medtronic. H. Sievert has received study honoraria to institution, travel expenses and consulting fees from 4tech Cardio, Abbott, Ablative Solutions, Adona Medical, Akura Medical, Ancora Heart, Append Medical, Axon, Bavaria Medizin Technologie GmbH, Bioventrix, Boston Scientific, Cardiac Dimensions, Cardiac Success, Cardimed, Cardionovum, Celonova, Contego, Coramaze, Croivalve, CSL Behring LLC, CVRx, Dinova, Edwards, Endobar, Endologix, Endomatic, Esperion Therapeutics, Inc., Hangzhou Nuomao Medtech, Holistick Medical, Intershunt, Intervene, K2, Laminar, Lifetech, Magenta, Maquet Getinge Group, Metavention, Mitralix, Mokita, Neurotronic, NXT Biomedical, Occlutech, Recor, Renal Guard, Shifamed, Terumo, Trisol, Vascular Dynamics, Vectorious Medtech, Venus, Venock, Vivasure Medical, Vvital Biomed and Whiteswell. M. Kühne received personal fees from Bayer, Böhringer Ingelheim, Pfizer BMS, Daiichi Sankyo, Medtronic, Biotronik, Boston Scientific, Johnson & Johnson, and F. Hoffmann-La Roche Ltd., as well as grants from Bayer, Pfizer, Boston Scientific, BMS, Biotronik, and Daiichi Sankyo. S. Sabir is part of the Boston Scientific WATCHMAN advisory board. J. Kim has received proctoring fees from Abbott Vascular. M. Montorfano received consultant fees from Abbott, Boston Scientific, Kardia. M. Ancona received consultant fees from Abbott. Relevant research funding went to Vanderbilt University Medical Center from Boston Scientific, Boehringer-Ingelheim, Medtronic and Atricure, where C. Ellis is practicing. He also reseves a consultant and advisor fee from Abbott Medical, Atricure, Boston Scientific, Medtronic. L. Nombela-Franco is proctor for Abbott Vascular and has received lectures fees from Boston Scientific. A. Natale has received speaker honoraria from Boston Scientific, Biosense Webster, St. Jude Medical, Biotronik, and Medtronic. He also is a consultant for Biosense Webster, St. Jude Medical, and Janssen.

All other authors declare that they have no competing interests.

REFERENCES

[1] Kirchhof P, et al. Guidelines for the management of atrial fibrillation developed in collaboration with EACTS. Europace. 2016. https://doi.org/10.1093/europace/euw295.

[2] Writing Group M, et al. AHA/ACC/HRS focused update of the 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. Heart Rhythm. 2019. https://doi. org/10.1016/j.hrthm.2019.01.024.

[3] Osmancik Pavel, et al. Interventional left atrial appendage closure vs novel anticoagulation agents in patients with atrial fibrillation indicated for long-term anticoagulation (PRAGUE-17 study); 2017.https://doi.org/10.1016/j.ahj.2016.10.003.

[4] Rebecca Brown Fountain, et al. The PROTECT AF (WATCHMAN Left Atrial Appendage System for Embolic PROTECTion in Patients with Atrial Fibrillation) trial; 2006.https://doi.org/10.1016/j.ahj.2006.02.005.

[5] Holmes Jr David R, et al. Prospective randomized evaluation of the Watchman Left Atrial Appendage Closure device in patients with atrial fibrillation versus long-term warfarin therapy: the PREVAIL trial; 2014.https://doi.org/10.1016/j.jacc.2014.04.029.

[6] SinghBajaj Navkaranbir, et al. Percutaneous left atrial appendage occlusion for stroke prophylaxis in nonvalvular atrial fibrillation: a systematic review and analysis of observational studies; 2014.https://doi.org/10.1016/j.jcin.2013.11.010.

[7] Wang Guangji, Kong Bin, Liu Yu, Huang He. Percutaneous retrieval of a dislocated LAmbre left atrial appendage occluder in a canine model; 2020.https://doi.org/10. 1111/jce.14344.

[8] Immohr Moritz B, Sugimura Yukiharu, Lichtenberg Artur, Akhyari Payam. Atrial thrombosis caused by a dislocated left atrial appendage closure device after mitral valve replacement; 2020.https://doi.org/10.1016/j.jaccas.2020.05.096.

[9] El-Gabry Mohamed, Shehada Sharaf-Eldin, Wendt Daniel, Mourad Fanar. Emergent surgical removal of a migrated left atrial appendage occluder; 2018.https://doi.org/10. 1093/ejcts/ezy005.

[10] Stöllberger Claudia, Schneider Birke, Finsterer Josef. Serious complications from dislocation of a Watchman left atrial appendage occluder; 2007.https://doi.org/10.1111/j. 1540-8167.2007.00784.x.

[11] Afzal Muhammad R, et al. Percutaneous approaches for retrieval of an embolized or malpositioned left atrial appendage closure device: A multicenter experience; 2020. https://doi.org/10.1016/j.hrthm.2020.04.024.

[12] Gaspardone Achille, et al. Percutaneous retrieval of a left atrial appendage closure device: The Device Waltz; 2021.https://doi.org/10.1016/j.jaccas.2021.02.034.

[13] Kany Shinwan, et al. Retrieval of embolised left atrial appendage closure devices; 2021. https://doi.org/10.4244/EIJ-D-19-01088.

[14] Aminian Adel, Lalmand Jacques, Tzikas Apostolos, Kefer Joelle. Embolization of left atrial appendage closure devices: A systematic review of cases reported with the watchman device and the amplatzer cardiac plug; 2015.https://doi.org/10.1002/ccd.25891.

[15] Murtaza Ghulam, Turagam Mohit K, Lakkireddy Dhanunjaya. Left atrial appendage occlusion device embolization (the LAAODE Study): Understanding the timing and clinical consequences from a worldwide experience; 2021.https://doi.org/10.4022/jafib.2516.

[16] Sandhu Amneet, et al. Device-sizing and associated complications with left atrial appendage occlusion: Findings from the NCDR LAAO Registry; 2022.https://doi.org/10. 1161/CIRCINTERVENTIONS.122.012183.

[19] Reddy Vivek Y, Doshi Shephal K, Kar Saibal, Gibson Douglas N, Price Matthew J, Huber Kenneth, et al. 5-Year outcomes after left atrial appendage closure: From the PREVAIL and PROTECT AF Trials; 2017.https://doi.org/10.1016/j.jacc.2017.10.021.

[20] Blackshear JL, Odell JA. Appendage obliteration to reduce stroke in cardiac surgical patients with atrial fibrillation; 1996. (doi:0.1016/0003-4975(95)00887-X).

[21] Mahajan Rajiv, et al. Importance of the underlying substrate in determining thrombus location in atrial fibrillation: implications for left atrial appendage closure; 2011. https://doi.org/10.1136/heartjnl-2012-301799.

[22] Goette Andreas, et al. EHRA/HRS/APHRS/SOLAECE expert consensus on atrial cardiomyopathies: Definition, characterization, and clinical implication; 2016.https://doi.org/10.1093/europace/euw161.

[23] Hochholzer W, Nührenberg T, Flierl U. Antithrombotische Therapie nach strukturellen kardialen Interventionen; 2020.https://doi.org/10.1007/s12181-020-00441-w.

[24] Zimetbaum P. Atrial fibrillation. Ann Intern Med. 2017;166(5):ITC33–48. https://doi.org/10.7326/AITC201703070.

[25] Freeman JV, et al. Cost-effectiveness of percutaneous closure of the left atrial appendage in atrial fibrillation based on results from PROTECT AF versus PREVAIL. Circ Arrhythm Electrophysiol. 2016. https://doi.org/10.1161/CIRCEP.115.003407.

[26] Aminian A, Chouchane I, Compagnie M, Decubber M, Lalmand J. Delayed and fatal embolization of a left atrial appendage closure device. Circulation: Cardiovascular interventions; 2014.

[27] Glikson Michael, Wolff Rafael. EHRA/EAPCI expert consensus statement on catheterbased left atrial appendage occlusion – an update. EuroIntervention. 2020. https://doi.org/10.4244/EIJY19M08_01.

[28] Mansour Mohamad Jihad, et al. Late discovery of left atrial appendage occluder device embolization: a case report; 2020.https://doi.org/10.1186/s12872-020-01589-9.

[29] Silva Manuela, Banazol Nuno, Fiarresga António, Fragata José. Embolization of percutaneous left atrial appendage occlusion device: Rescue surgery; 2021..

[30] Dukkipati Srinivas R, et al. Device-related thrombus after left atrial appendage closure: incidence, predictors, and outcomes; 2018.https://doi.org/10.1161/CIRCULATIONAHA.118. 035090.

[31] Garot Philippe, Iriart Xavier, Aminian Adel, De Backer Ole. Value of FEops HEARTguide patient-specific computational simulations in the planning of left atrial appendage closure with the Amplatzer Amulet closure device: rationale and design of the PREDICT- LAA study; 2020.https://doi.org/10.1136/openhrt-2020-001326.

[32] Saw Jacqueline, et al. Comparing measurements of CT angiography, TEE, and fluoroscopy of the left atrial appendage for percutaneous closure; 2016.https://doi.org/10. 1111/jce.12909.

[33] Neuzner Joerg, Dietze Thomas, Paliege Robert, Gradaus Rainer. Left atrial appendage closure with the AmplatzerTM Cardiac Plug: Rationale for a higher degree of device oversizing at implantation; 2014.https://doi.org/10.5603/CJ.a2014.0063.

[34] Menne Matthias F, et al. Mechanical properties of currently available left atrial appendage occlusion devices: A bench-testing analysis; 2019.https://doi.org/10.1111/aor.13414.

[35] Salmon Mandy K, et al. Correction to: Left atrial appendage occlusion with the Amulet device: to tug or not to tug?; 2021.https://doi.org/10.1007/s10840-020-00839-2.

[36] Chopra Manik, Wong Yam-Hong, Søndergaard Lars, De Backer Ole. Percutaneous retrieval of an embolized left atrial appendage closure device from the left atrium in a patient with previous MitraClips; 2019.https://doi.org/10.1186/s12872-019-1170-8.