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Left Atrial Occlusion Device Implantation: the Role of the Echocardiographer

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Abstract

Purpose of Review Atrial fibrillation is the most common arrhythmia worldwide and is a major risk factor for embolic stroke. For patients with atrial fibrillation who are unable to tolerate systemic anticoagulation, left atrial appendage (LAA) occlusion has been shown to mitigate stroke risk. In this article, we describe the vital role of the echocardiographer in intraprocedural guidance of percutaneous LAA occlusion procedures as well as in the pre- and post-procedure assessment of these patients.

Recent Findings A few percutaneously delivered devices for LAA exclusion from the systemic circulation are available in contemporary practice. These devices employ an either exclusive endocardial LAA occlusion approach, such as the Watchman (Boston Scientific, Maple Grove, MN) and Amulet (St. Jude Medical, Minneapolis, MN), or both an endocardial and pericardial (epicardial) approach such as the Lariat procedure (SentreHEART, Palo Alto, CA).

Summary Two- and three-dimension transesophageal echocardiography is critical for patient selection, procedure planning, procedural guidance, and ensuring satisfactory immediate as well as long-term LAA occlusion/exclusion efficacy. This review will provide an overview of the role of the echocardiographer in all aspects of LAA occlusion/exclusion procedures for the most commonly used commercially available devices in current practice.

Keywords Left atrial appendage · Echocardiography · 3D · Percutaneous closure

Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia, affecting more than 3 million individuals in the USA alone. As the prevalence of AF increases with age and with the improved longevity of our population, the incidence of AF is projected to increase dramatically by midcentury [1].

AF is associated with significant morbidity, increased mortality as well as substantial personal, and societal and economic cost. It is estimated that AF costs the USA 6 billion dollars annually [2].

The most devastating complication of AF is systemic thromboembolism, particularly stroke. The left atrial appendage (LAA) is the most common site of thrombus

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formation, accounting for 91% of thrombi in patients with nonvalvular atrial fibrillation and 57% of thrombi in patients with valvular AF related to rheumatic heart disease [3].

Systemic anticoagulation using warfarin with a goal international normalized ratio (INR) of 2–3 has been demonstrated to reduce the risk of stroke and systemic embolization by 67% when compared with placebo [4] and by 45% when compared with aspirin [5]. New direct oral anticoagulants (DOACs; such as dabigatran, apixaban, and rivaroxaban) have been shown to be at least noninferior to warfarin in nonvalvular AF in recent randomized controlled trials [6–8].

While systemic anticoagulation remains the gold standard for stroke prevention in AF, these agents are contraindicated in certain patients. The anticoagulants all carry significant bleeding risks. The risk for major bleeding (defined as a reduction in the hemoglobin level of at least 2 mg/dl, transfusion of 2 units of packed red blood cells, bleeding occurring at a critical site or resulting in death) is estimated from 1.4 to > 3% per year [9].

Since the majority of thrombi that form in patients with nonvalvular AF develop in the LAA, exclusion/occlusion procedures have been pioneered as alternatives to systemic anticoagulation. These procedures are designed to avert LAA thrombi from entering the systemic circulation [10–12, 13••].

Percutaneous LAA occlusion/exclusion devices include the Watchman (Boston Scientific, Maple Grove, MN), Amplatzer LAA occluders (Cardiac Plug (ACP)), Amulet (St. Jude Medical, Minneapolis, MN) [14•,15,16•], and the Lariat (SentreHEART, Palo Alto, CA) [17•,18,19].

In the USA, the Watchman device is presently the only device approved for LAA occlusion by the Food and Drug Administration (FDA). The Lariat has received class II clearance by the FDA through the 510(K) protocol. While the device is not specifically approved for percutaneous LAA exclusion, it is increasingly used for this application in clinical practice.

The Amplatzer Cardiac Plug seminal trial was discontinued due to slow enrollment. However, the Amplatzer Amulet device, St. Jude Medical's second-generation device, is currently being investigated in the USA as part of the Amulet trial. Many other LAA occluders are in development including the WaveCrest device [20].

The Watchman, Amplatzer Cardiac Plug, and Amulet devices are all delivered using peripheral venous access and transseptal puncture, completely endovascular. The Lariat procedure, however, utilizes both an endocardial and pericardial (epicardial) method to create a magnetic connection between endocardial and pericardial wires with subsequent epicardial exclusion of the LAA.

One additional device is capable of LAA ligation using an endocardial and pericardial technique is the LASSO device (Aegis Medical Innovations, Vancouver, Canada). This approach uses electrical mapping as opposed to a magnetic link to locate and ligate the LAA. It is currently being investigated in the open-label LASSO AF Trial.

This review is aimed at discussing the role of two-dimensional (2D) and three-dimensional (3D) transesophageal echocardiography (TEE) for the periprocedural guidance of the percutaneous LAA occlusion/exclusion devices either commercially available or under clinical investigation in the USA, specifically the Watchman, Amulet, and Lariat [13••].

Left Atrial Appendage Anatomy

The left atrial appendage is a complex structure that originates from the anterolateral portion of the left atrium. Its entrance is defined by an ovoid orifice and therefore has a major and minor orifice diameter. This orifice opens to a neck region, followed by a body, and terminates in the LAA apex. Notably, the LAA orifice is typically distinct from the landing zone of the various LAA occluder devices—which will be addressed in detail with each individual device below. The LAA orifice is separated from the left-sided pulmonary veins by the ligament of Marshall (also known as the coumadin ridge) [21, 22•],

The LAA has extraordinary anatomic variability [23]. It is important to recognize the number of lobes of the LAA (defined as protrusions from the main body) and to distinguish the LAA type. The most frequently seen morphologies of the LAA are the windsock, broccoli (or cauliflower), the cactus, and the chicken wing. Of the various LAA morphologies, the chicken wing is the most common [24]. Unfortunately, the chicken wing LAA is also the most technically challenging morphology for successful LAA occlusion/exclusion owing to its often broad width and shallow depth.

LAA anatomy should be established during the screening evaluation using cardiac-gated computed tomography angiography (CTA). It may also be confirmed using intraprocedural TEE and fluoroscopy (Fig. 1).

Fluoroscopic and TEE Views of LAA

In the procedural suite, it is crucial that the proceduralist and echocardiographer are working in sync. This begins with ensuring appropriate orientation to the LAA on both fluoroscopic and TEE images. RAO caudal is equivalent to approximately 135° on TEE and typically reveals the

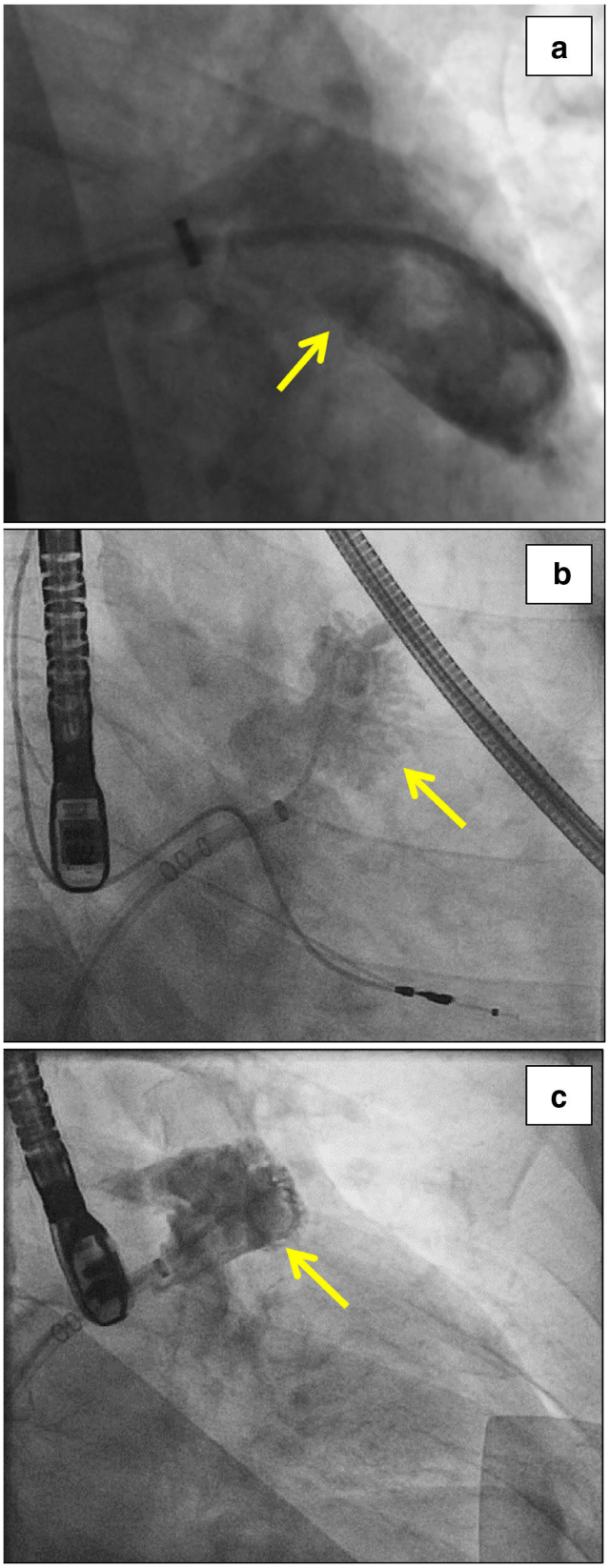

Fig. 1 Variety of LAA shapes on fluoroscopy. **a** Windsock. **b** Cauliflower. **c** Chicken wing. Yellow arrows point to the LAA

major axis of the LAA orifice. RAO cranial is equivalent to approximately 45° on TEE and typically reveals the minor axis of the LAA orifice.

Overview of Percutaneous LAA Occlusion/Exclusion Procedures

The initial steps of LAA occlusion/exclusion regardless of the device being used are shared. All procedures begin with systemic venous access, typically through the right femoral vein. Subsequently, the transseptal puncture is performed to gain access to the LAA. At this point, the next steps are unique to each individual device.

Transseptal Puncture Overview

After femoral venous access, a transseptal needle delivery catheter and dilator are passed through the inferior vena cava, into the right atrium, and then placed into the superior vena cava. Next, the transseptal puncture needle is advanced through the delivery catheter.

Under TEE guidance, the system is then removed from the super vena cava, brought into the right atrium, and positioned against the inferior and posterior portion of the interatrial septum. Appropriate location is ensured with both fluoroscopic and TEE visualization before the needle is advanced, creating the transseptal puncture.

The inferior and posterior position is preferred (Fig. 2**)** as this allows for the most direct route to the LAA, located anterolaterally in the left atrium (LA). Importantly, this transseptal puncture is different from the preferred superior and posterior transseptal puncture utilized during MitraClip (Abbott Vascular, Abbott Park, Illinois) and transcatheter mitral valve replacement.

Once the transseptal puncture is performed, the dilator and the sheath are advanced into the left atrium. A wire is brought into the LA and typically positioned in the left superior pulmonary vein; the dilator and sheath are then removed.

Role of Echocardiographic Guidance for Transseptal Puncture

Using 2D and 3D TEE, assessment of the interatrial septum initially includes identification of the fossa ovalis. The fossa position, thickness, and mobility must be noted. Next, a color Doppler imaging is utilized to assess for baseline patent foramen ovale (PFO) or atrial septal defect (ASD). While the transseptal puncture can be performed using operator tactile feedback and fluoroscopy, echocardiographic imaging using

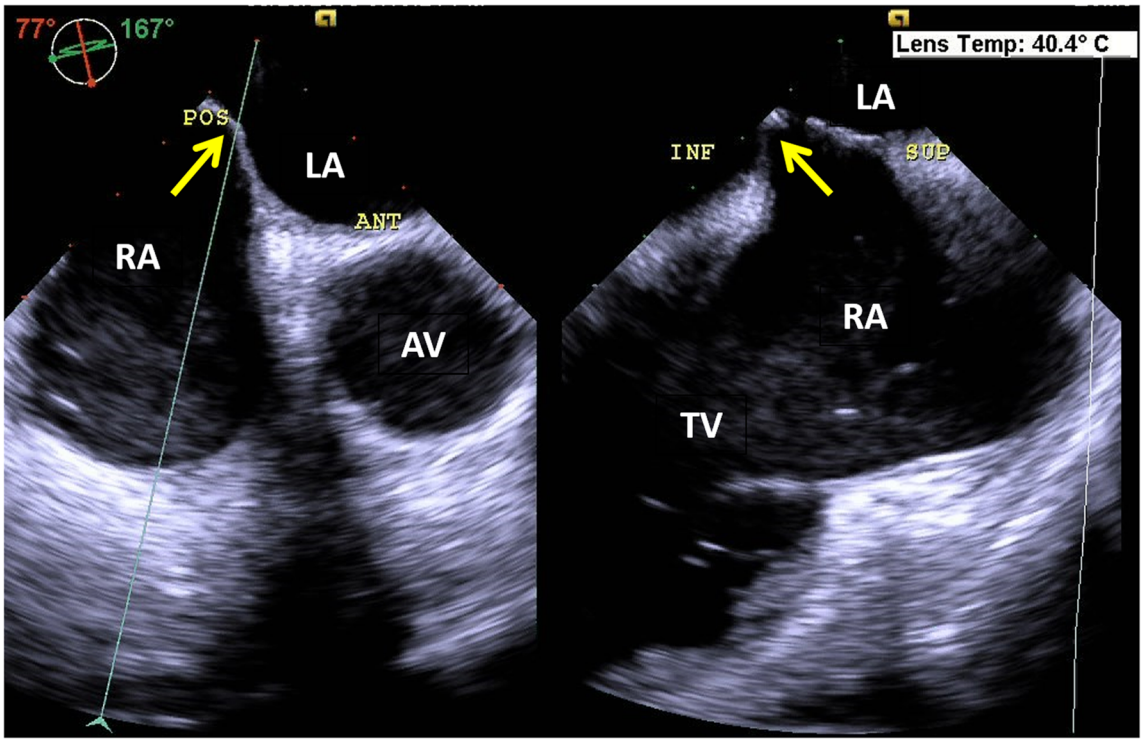

Fig. 2 Transseptal puncture. Simultaneous biplane TEE view of the interatrial septum. Yellow arrows point to tenting of the posterior and inferior aspects of the interatrial septum which is the preferred location for the transseptal puncture during percutaneous closure of LAA. Ant, anterior; AV, aortic valve; Inf, inferior; LA, left atrium; Pos, posterior; RA, right atrium; Sup, superior; TV, tricuspid valve

2D TEE, 3D TEE, or intracardiac echocardiography (ICE) improves the safety and success rate [25].

With biplane imaging of the interatrial septum (anterior-posterior position in one plane, superior-inferior position in the other), the transseptal needle is guided towards the inferior and posterior portion of the fossa ovalis. Prior to performing the puncture, the needle assembly should be advanced onto the septum, causing tenting at the proposed site of the puncture, to confirm satisfactory position. It is critically important that the transseptal puncture is performed in the inferior and posterior aspects of the interatrial septum.

In order to aid with procedural success, it is helpful to label the superior, inferior, anterior, and posterior aspects of the fossa ovalis on echocardiographic images for the proceduralist's orientation (Fig. 2**).**

After the transseptal puncture has been performed, TEE with 3D zoom of the interatrial septum may be used to confirm satisfactory position of the puncture. A detailed approach for the production of high-quality views of the interatrial septum has been previously described using the TUPLE (tilt up, then left) maneuver [13••, 26].

Atrial septal aneurysm and marked lipomatous hypertrophy of the interatrial septum should be noted as these may pose technical challenges to a successful transseptal puncture. Large atrial septal aneurysm may lead to excessive advancement of the transseptal needle and subsequent perforation of the left atrial free wall. With lipomatous hypertrophy, it is crucial to guide the transseptal needle through the thin central portion of the fossa ovalis rather than the hypertrophied limbs [27].

Watchman Procedure

The Watchman is a self-expanding nickel titanium device with fixation barbs, covered by a permeable polyester fabric. It is available in 5 sizes (21 mm, 24 mm, 27 mm, 30 mm, 33 mm) based on the device diameter on its left atrial side.

The procedure begins with venous access and the transseptal puncture as previously described. Next, the 12 French Watchman delivery system with a pigtail catheter is advanced into the LA over the wire and positioned into the LAA. LAA anatomy is subsequently defined fluoroscopically with a small injection of iodinated contrast. The Watchman device is then positioned and delivered into the LAA. Finally, the device is released after stability and optimal position is confirmed by both echocardiography and cine-fluoroscopy [13••].

The Watchman device has been demonstrated noninferior to chronic warfarin therapy in a randomized trial [15]. Possible procedural complications include pericardial effusion, device embolization, and procedure-related stroke [28]. After device implantation, patients typically require warfarin for 45 days, followed by dual antiplatelet therapy (with aspirin and clopidogrel) for 6 months, followed by aspirin alone [13••, 15].

Baseline Assessment

The echocardiographic assessment focuses on excluding any preexisting intracardiac thrombus (presence of which would lead to procedure cancelation) and baseline degree of pericardial effusion, as well as anatomic characteristics of the LAA and interatrial septum. The presence of any significant valvular abnormalities, mobile aortic atheroma (> 4 mm), and intracardiac shunt is also established.

LAA Anatomic Exclusion Criteria for Watchman Device

- LAA orifice diameter either too small (< 16.8 mm) or too large (> 30.4 mm)
- LAA depth too shallow (LAA depth < largest LAA orifice diameter)
- Depth of secondary LAA lobe (if present) < 1 cm from the LAA orifice, as this can lead to an uncovered portion of the LAA

Other Possible Exclusion Criteria

- Atrial septal aneurysm excursion distance > 15 mm
- Large interatrial shunt. No specific criteria currently exist to define a large shunt in this setting
- Mobile aortic plaque > 4 mm in thickness
- Significant mitral stenosis (mitral valve area < 1.5 cm^2)
- Pericardial effusion with thickness > 2 mm

Watchman Sizing

The LAA landing zone size and LAA depth are measured during the baseline assessment for the Watchman procedure. On 2D TEE imaging, the LAA is measured at 0°, 45°, 90°, and 135°. Measurements are made at each angle to define the maximal diameter of the expected landing zone. The LAA landing zone is measured from the top of the mitral valve annulus or circumflex coronary artery to a point 2 cm below the left upper pulmonary vein limbus. Depth is measured from the plane of the LAA orifice to the LAA apex (Fig. 3).

Due to the tomographic nature of 2D imaging, multi-plane reconstruction (MPR) 3D imaging may be utilized to improve accuracy of the landing zone diameter. In MPR mode, two long axes of the LAA are aligned to visualize the short axis, thereby allowing for precise measurement.

At this point, the Watchman is sized based on the largest landing zone dimensions measured. The device is typically oversized relative to the largest measured LAA diameter by up to 20%.

Watchman Placement

After the transseptal puncture, the Watchman delivery system including a pigtail catheter is advanced into the LA. The delivery system is guided into the LAA with both fluoroscopy and 2D or 3D TEE. 3D TEE has the benefit of allowing for visualization of the entire lengths of the catheters as they cross the LA to reach the LAA. TEE also provides assessment of the distance between the catheter tips and the transseptal puncture site to prevent accidental decannulation back into the right atrium [13••].

After the guide catheter is placed in the LA, the pigtail catheter is advanced to the LAA. Subsequently, the pigtail is used to perform contrast angiography to assess the LAA fluoroscopically.

The guide catheter/pigtail combo is then navigated such that the corresponding radio-opaque marker for the Watchman device is aligned with the LAA ostium. The pigtail catheter is then removed and the Watchman device is unsheathed slowly, but remains attached to the delivery cable. This is done under TEE guidance.

Watchman Device Release

Prior to device release, the "4 PASS" criteria (Position, Anchor, Size, and Seal) must be met [22•].

- *Position*. The "shoulder" of the device (curved portion at the level of the LAA orifice) should protrude less than 40–50% of the device depth out of the LAA and into the LA.
- *Anchor*. A "tug test" is performed. The deployment knob is retracted and the device is let go under direct (TEE or fluoroscopic) visualization to confirm that the device returns to its original position.
- *Size*. The device diameter compression is obtained by 2D TEE at 0°, 45°, 90°, and 135°. The compression is measured from the device "shoulder to shoulder," while ensuring the central metallic portion of the LA side of the device (the threaded insert) is in view. This should be 8–20%.
- *Seal*. Assessment for para-device leak (PDL) vena contracta is performed by 2D TEE with color Doppler at 0°, 45°, 90°, and 135°. The vena contracta of the PDL is the thinnest cross section in the plane where the device is closest to the LAA wall. A PDL vena contracta < 5 mm is considered acceptable. When the PDL is ≥ 5 mm, the Watchman device should be recaptured and either repositioned or replaced with a larger device [22•]. A low Nyquist limit (20–30 cm/s) is crucial to detect low-velocity flow and increase detection sensitivity [29]. 3D TEE with color Doppler imaging can also be used to assess the circumferential extent of PDL [13••].

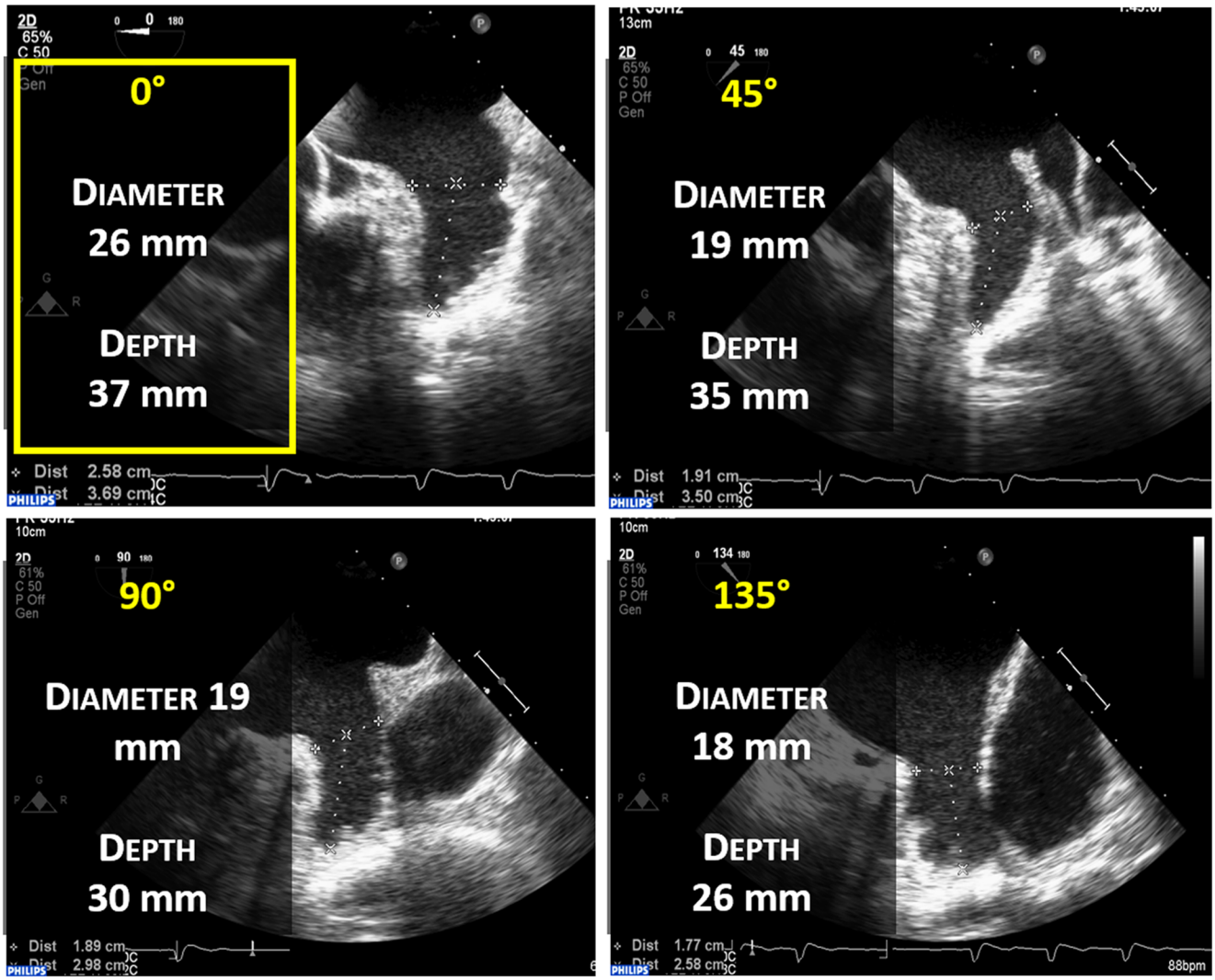

Fig. 3 LAA sizing for Watchman device. 2D TEE imaging of the LAA at 4 typical angles (0°, 45°, 90°, and 135°). LAA ostial diameter and depth are measured at each angle and the largest LAA diameter (in this case at 0°) is used to select the appropriate Watchman device size

After the Watchman device is deployed, the catheters are withdrawn into the right atrium with subsequent removal from the body. Color Doppler should then be applied to the interatrial septum to evaluate for procedure-related ASD at the site of the transseptal puncture. An ASD of < 10 mm is considered acceptable. An ASD > 10 mm is rare and may require percutaneous ASD closure. The Watchman procedure is illustrated in Fig. 4.

Immediate Complications

Pericardial effusion (PEF) is the most important complication to assess with echocardiography. PEF typically occurs from perforation of one of the cardiac chambers or the LAA.

Interrogation from multiple windows is important to evaluate for PEF, specifically, the transgastric views and the midesophageal 4-chamber view with clockwise rotation of the probe to focus on the RV-RA junction. Comparison with the baseline PEF size (if present) is crucial. Notably, it is important to distinguish prominent pericardial fat pad from effusion.

The rate of PEF related to the Watchman procedure has been reported at 2.2–5%. This has decreased over time, likely related to increased operator experience as well as the use of a pigtail catheter to avoid blunt trauma to the LAA from the guide catheter [25].

The rarer immediate complications are device embolization and periprocedural stroke. Device embolization can be readily identified on TEE. Presence of thrombus in the left atrium, on the device, or on any of the delivery equipment may portend periprocedural stroke.

Watchman Post-Procedure Follow-Up

It takes approximately 45 days for Watchman device endothelialization. Therefore, a 45-day follow-up TEE

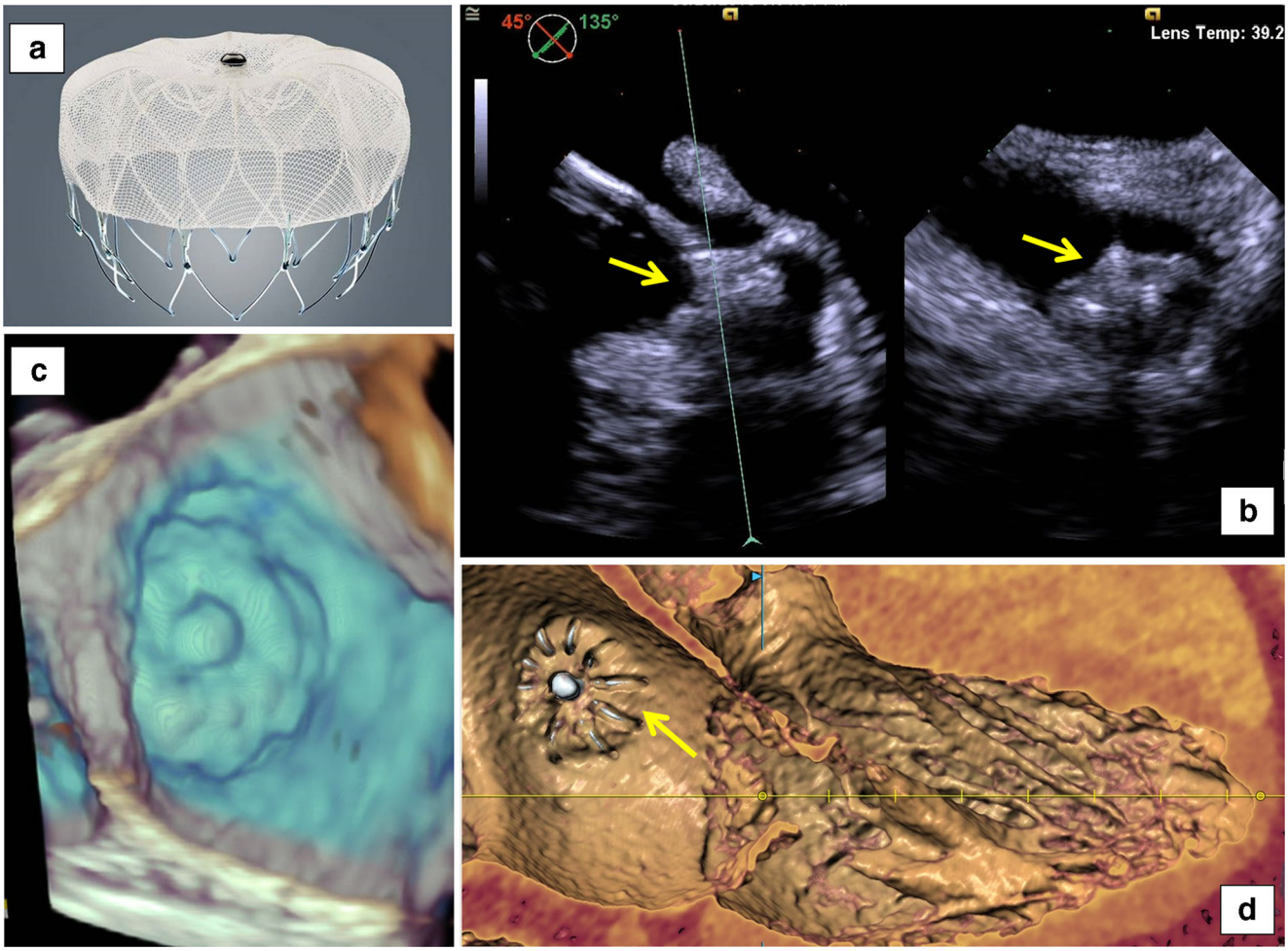

Fig. 4 Watchman device. **a** Photograph of a Watchman device. **b** Simultaneous biplane TEE view of the Watchman device (yellow arrows) as it is being deployed inside the LAA. **c** 3D TEE en face view of a fully deployed Watchman device. **d** 3D CT rendering of a deployed and endothelialized Watchman device (yellow arrow)

examination was performed in the large clinical trials evaluating the Watchman and is now replicated in clinical practice [13••, 15, 30].

Major goals of the 45-day follow-up TEE:

- *Reassess device position and stability.* TEE imaging is typically performed at 0°, 45°, 90°, and 135° to confirm device position.
- *Assess for any residual or new para-device leak* (*PDL*). TEE imaging is again performed at 0°, 45°, 90°, and 135° with color Doppler and a low Nyquist limit, as described above. A PDL < 5 mm is common and occurs in approximately 1/3 of patients. Importantly, PDL < 5 mm has not been found to correlate with an increased risk of thromboembolism and therefore, continuation of anticoagulation in these patients is currently not recommended [31].
- *Assess for thrombus*. While thrombus is expected within the excluded LAA (distal to the device), identification of device-associated thrombus is of critical importance. Device-associated thrombus is located on the LA side of the device. These most commonly occur on the Watchman device–threaded insert due to possible delayed endothelialization at this site. Thrombus has also been seen on uncovered LAA trabeculations. Device-associated thrombi are uncommon, occurring in 3.7% of patients in the PROTECT-AF study [32]. Importantly, in patients with device-associated thrombus, there was a 15% incidence of associated ischemic stroke [25].
- *Look for residual shunt across the interatrial septum*. Typically, the septum heals post-transseptal puncture and the majority of procedural-related ASDs are either partially or completely sealed at this time. An ASD greater than 10 mm in diameter may need to be percutaneously closed.
- *Perform a complete study.* It is important to note any changes from the baseline study, and thoroughly investigate, if present. Presence of significant pericardial effusion and disruption of any other structure due to the device (i.e., from erosion, embolization, or infection) are necessary to exclude [13••, 33].

Amulet Procedure Overview

The Amulet is the second-generation LAA occlusion device from Amplatzer. Its main component is a self-expanding nitinol mesh in a lobe and disc configuration connected by an articulating waist. Both the lobe and disc are covered by a hand-sewn polyester mesh. The anchor of the Amulet device is the lobe; this is positioned approximately 10-12 mm into the LAA (distal to the LAA orifice). Stabilizing wires are utilized to secure the device in place. In an effort to reduce device-related thrombus, the central proximal end screw is recessed (analogous to the Watchman-threaded insert) [13••].

With the lobe contained within the LAA, the disc is placed in the left atrium adherent to the LAA orifice—effectively sealing the LAA. The Amulet comes in 8 sizes, corresponding to the lobe diameter (16 mm, 18 mm, 20 mm, 22 mm, 28 mm, 31 mm, and 34 mm).

It is important to note that disc diameters are equivalent to the lobe diameter + 6 mm for the Amulet sizes 16–22 mm, and lobe diameter + 7 mm for sizes 25–34 mm. Waist lengths are 5.5 mm for sizes 16–22 mm and 8 mm for sizes 25–34 mm.

Compared with the Watchman, the Amulet device can be used for both larger and smaller LAA orifices. At the upper end, the Amulet is suitable for LAA diameters up to 32 mm vs 30.4 mm for the Watchman. On the lower end, the Amulet is suitable for LAA diameter as small as 14 mm vs. 16.8 mm for the Watchman.

Comparable with the Watchman device, the Amulet procedure begins with transfemoral venous access followed by the transseptal puncture. Next, a delivery sheath is advanced into the left atrium and positioned in the LAA. The "landing zone" of the LAA is then identified approximately 10-12 mm distal to the LAA ostium. The delivery sheath is positioned into this landing zone, and the Amulet device is subsequently advanced to the tip of the sheath. The device is then deployed and if the position is satisfactory, the system is released [34].

There is currently only observational data available for the Amulet device. This data has shown high implant success rates and low periprocedural and early adverse events [35]. A larger, randomized trial (the AMULET) is currently underway in the USA to evaluate the safety and efficacy of the Amulet as compared with the Watchman [22•].

Baseline Assessment

The LAA is imaged at 0°, 45°, 90°, and 135° on 2D TEE. It is recommended to focus on the "short axis" (the minor diameter axis of the ovoid LAA orifice, typically between 30° and 60°) and the "long axis" (the major diameter axis of the ovoid LAA orifice, typically between 120° and 150°).

For the Amulet, sizing measurements differ from the Watchman. The LAA ostial diameter is defined as the line from the pulmonary vein ridge to the circumflex artery [36]. The landing zone diameter is then measured 10–12 mm distal to the ostium at an angle perpendicular to the neck axis. Amulet device sizing is based primarily on the landing zone diameter measurement.

The depth measurement for the Amulet is measured perpendicular to the plane of the LAA orifice towards the back LAA wall (along the so-called neck axis). This is different than the depth measurement for the Watchman, which is measured from the plane of the LAA orifice diameter towards the LAA apex [13••].

LAA Anatomic Exclusion Criteria for Amulet Device

- LAA landing zone diameter > 32 mm or < 14 mm
- LAA depth < 10 mm for 16–22-mm Amulet devices
- LAA depth < 12 mm for 25–34-mm Amulet devices

Other Exclusion Criteria for Amulet Device

- Intracardiac thrombus
- Cardiac mass or tumor
- Large interatrial shunt (> 20 bubbles that appear within 3 beats on agitated saline injection)
- Atrial septal aneurysm with excursion > 15 mm
- Complex atheroma with mobile plaque in the aortic arch or descending aorta
- Mitral stenosis with valve area < 1.5 cm^2
- Moderate or large pericardial effusion (thickness > 2 mm)
- Placement of the device would interfere with any intracardiac or intravascular structure [22•]

Echocardiographic Guidance for the Amulet Procedure

The transseptal puncture for the Amulet should be in the inferior and posterior position. After the wire is placed in the left superior pulmonary vein, the access sheath is positioned in the LA. The Amulet has two access sheath sizes, 12 French (for 16–28-mm Amulet sizes) or 14 French (31 and 24-mm Amulet sizes).

Next, the wire is removed from the pulmonary vein while the sheath remains in the LA. The sheath is then advanced with its tip at the LAA landing zone. At this point, the Amulet device is moved to the distal point of the access sheath and then, the lobe is partially deployed.

The semi-deployed portion of the Amulet device is called the ball. The ball is formed in the body of the LA and then advanced into the LAA landing zone where it is fully deployed. If the angle and position of the fully deployed lobe are satisfactory, the Amulet disc is then deployed.

Amulet Device Release

Prior to device release, the following 5 criteria must be met:

1. The lobe should be tire-shaped to ensure appropriate compression and engagement of stabilizing wires.
2. There should be a degree of separation between the lobe and the disc to ensure a good seal.
3. The disc should be concave relative to the body of the left atrium to ensure a good seal.
4. The axis of the lobe should be perpendicular to the neck axis to ensure stability.
5. At least two thirds of the lobe should be positioned adjacent to the circumflex artery. To confirm stability, a gentle pull-test of the disc can be performed [13••].

Similar to the Watchman, para-device leak is assessed using color Doppler with a low Nyquist limit (35–45 cm/s). A small leak is defined as a jet less than 3 mm in diameter or multiple jets whose collective size is less than 3 mm in diameter. Medium and large leaks are jet diameters (or cumulative jet diameters) of 3–5 mm or greater than 5 mm, respectively. The Amulet procedure is illustrated in Fig. 5.

Immediate Complications

The immediate complications that may be experienced with the Amulet device are similar to the Watchman. The rate of stroke was 0.3%, device embolization 0.1%, pericardial effusion 0.5%, and procedural bleeding 0.7%

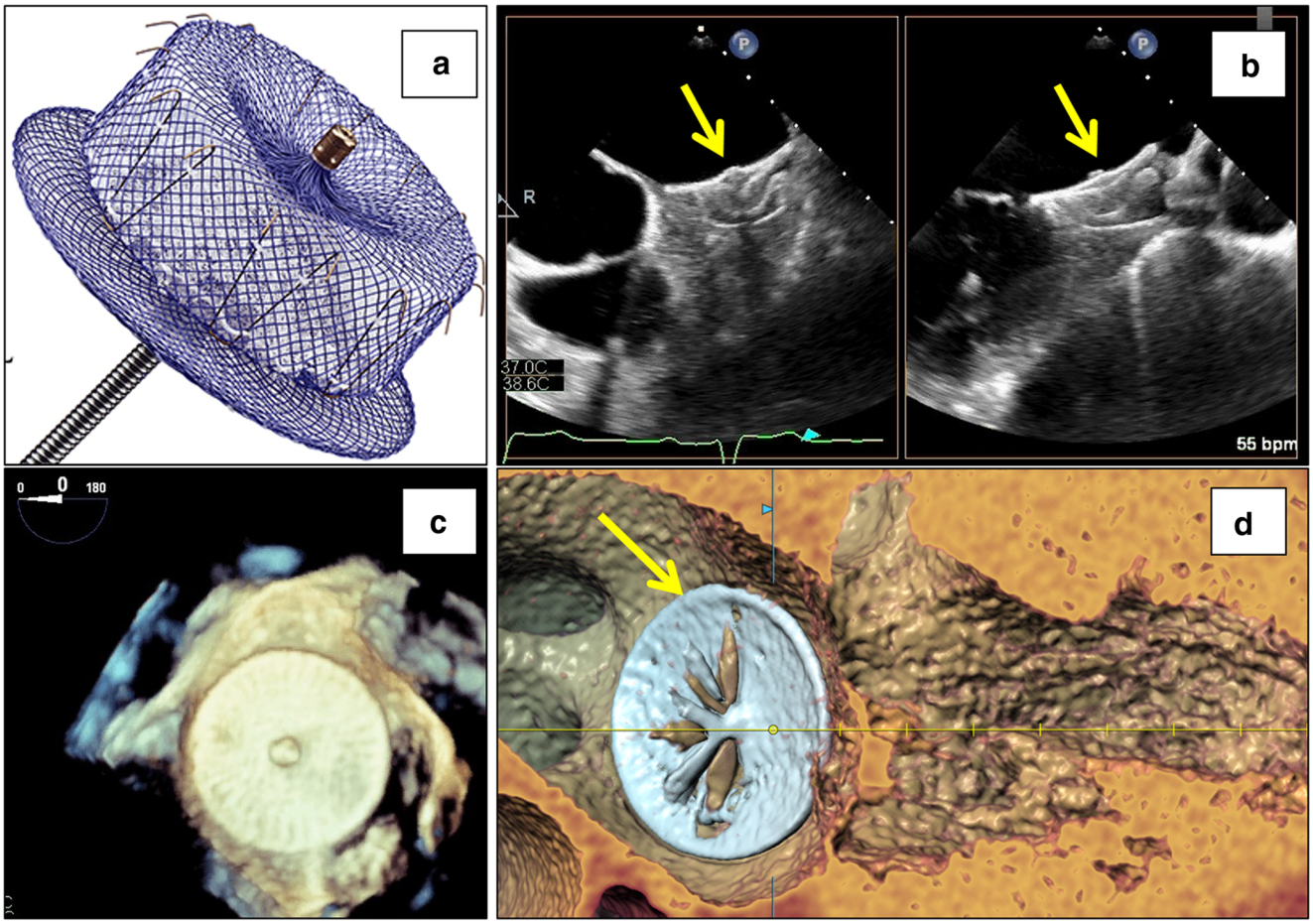

Fig. 5 Amulet device. **a** Photograph of an Amulet device. **b** Simultaneous biplane TEE view of the Amulet device (yellow arrows) deployed inside the LAA. **c** 3D TEE en face view of a fully deployed Amulet device. **d** 3D CT rendering of a deployed Amulet device (yellow arrows)

in the largest observational study evaluating the Amulet device [37].

Amulet Post-Procedure Follow-up

Post-procedural TEE follow-up is performed at 45 days post-Amulet implantation. The focus is the same as for the Watchman—evaluation for device stability and position, PDL, device-related thrombus, pericardial effusion, and iatrogenic ASD. A complete study should also be performed to assess for any significant changes from the procedural TEE.

The Lariat Procedure

The Lariat device is comprised of endocardially and epicardially delivered magnetic-tipped wires that meet at the distal LAA wall. This creates a rail for delivery of a pre-tied suture that ligates the LAA. Since long-term safety and efficacy data are lacking [16•, 17•, 18, 38], the aMAZE (LAA ligation Adjunctive to Pulmonary Vein Isolation for Persistent or Longstanding Persistent Atrial Fibrillation) Trial is currently ongoing.

Lariat Device: Baseline Comprehensive Assessment and Exclusion Criteria

The baseline assessment of the Lariat is similar to that of the previously described devices. However, precise delineation of the LAA position and maximal body width, typically at angulation of 135° or higher, are crucial.

A body width of greater than 45 mm or a superiorly oriented LAA with its apex behind the pulmonary trunk makes the Lariat exceedingly technically challenging and is considered exclusion criteria. Other exclusion criteria include prior cardiac surgery, myocardial infarction within the past 3 months, embolic events within the past 30 days, or a history of pericarditis.

Pericardial/Epicardial Access

The epicardial portion of the Lariat procedure is typically guided by fluoroscopy. However, monitoring the right ventricle during pericardial access can be useful to evaluate for RV puncture. This is typically best demonstrated in the midesophageal short-axis view.

Echocardiographic Guidance for the Lariat Procedure

2D and 3D guidance of the transseptal puncture for the Lariat procedure is similar to the devices detailed above. After a successful transseptal puncture, a wire is inserted into the LAA and the dilator and sheath are removed. Next, an 8.5 French SL1 catheter (St. Jude Medical, Minneapolis, MN) is advanced into the LAA. 3D TEE can be used to monitor catheter and wire positions to help prevent accidental decannulation. Then, a 15-mm balloon-tipped catheter (EndoCATH; SentreHEART, Palo Alto, CA) back-loaded with a magnet-tipped guidewire is brought through the guide catheter (SL1) into the LAA under both TEE and fluoroscopic guidance. The balloon-tipped catheter and magnet-tipped wire are then advanced into the LAA, with the catheter remaining at the ostium of the LAA while the magnet-tipped wire is maneuvered into the LAA apex. The balloon on the EndoCATH catheter is subsequently inflated to facilitate ensnarement of the LAA [39].

Next, the epicardial Lariat device is positioned so that the radiopaque marker on its distal tip is appropriately oriented to the magnet-tipped wire within the LAA, thereby creating a magnetically linked rail. The Lariat snare is then brought via this magnetic rail epicardially, over the LAA to its ostium and tightened, using the inflated balloon within the LAA for support. After the snare is tightened, the balloon is deflated and the EndoCATH balloon and magnet-tipped wire within the LAA are withdrawn into the LA. Then, the epicardial Lariat suture is cinched and secured around the LAA, thereby excluding the LAA from the systemic circulation [13••].

Color Doppler is utilized to assess for any significant communication between the LA and the LAA. Notably, a small amount of color Doppler flow around the balloon-tipped catheter is normal. Once satisfactory positioning is confirmed, the EndoCATH balloon is deflated, the catheter and wire are then removed from the LAA and the suture is tightened. At this point, there should be less than 5 mm in width of color Doppler flow between the LAA and the LA using a low Nyquist limit.

On 3D TEE, the successfully ligated LAA has a "bowtie" appearance. Multi-plane imaging at 0°, 45°, 90°, and 135° should be performed to visualize the entire excluded LAA orifice. 3D TEE with color Doppler imaging can aid in the assessment of residual LA-LAA communication.

After Lariat device deployment, the delivery catheter is withdrawn and an assessment of the state of the interatrial septum is performed, similar to the previously described devices [40••]. The Lariat procedure is illustrated in Fig. 6.

Immediate Complications

The most common complication is pericarditis which is typically transient; only 2.4% of patients were found to have persistent pericarditis [41]. Pericardial effusion is the most dangerous potential complication and should be assessed by 2D TEE in multiple views. Reported rate of PEF is 3.7–5% during Lariat [17•, 33]. Development of a significant pericardial effusion may necessitate abortion of the procedure. However, if

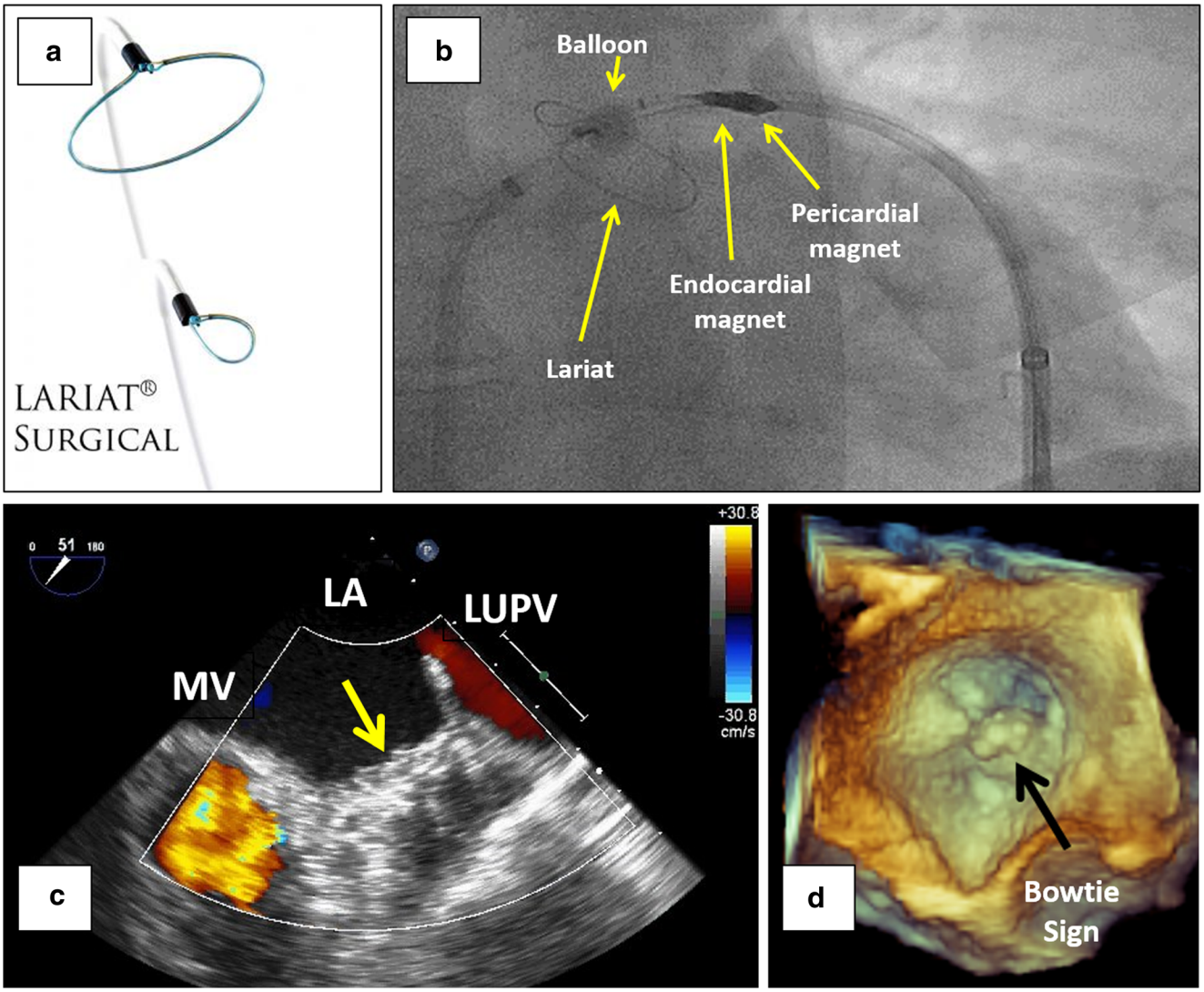

Fig. 6 Lariat procedure. **a** Photograph of a Lariat device. **b** Fluoroscopy of Lariat assembly in an RAO view. **c** 2D TEE image demonstrates completed closure of LAA (yellow arrow) post-Lariat procedure. **d** 3D TEE en face view of closed LAA post-Lariat procedure with a characteristic "bowtie" appearance. The black arrow points to one part of the excluded LAA. LA, left atrium; LAA, left atrial appendage; LUPV, left upper pulmonary vein; MV, mitral valve

the etiology of the PEF is from LAA perforation, completing the Lariat procedure may actually be a therapeutic option [42].

Lariat Device: Post-Procedural Follow-Up

There is no standardized routine follow-up recommended for the Lariat device and current clinical practice is variable. We recommend a protocol that emulates the aMAZE Trial, with TEE at 30 days, 1 year, 2 years, and 3 years post-procedure.

The focus is similar to the previously described follow-up exams—ensure satisfactory LAA ligation (< 5 mm color Doppler flow between the LAA and LA) as well as exclude device-related thrombus and pericardial effusion. A comprehensive TEE is recommended to identify any significant changes from the pre-procedural TEE.

Conclusion

Percutaneous LAA occlusion/exclusion devices are being implanted at increasing rates to reduce stroke risk for patients unable to tolerate or ineligible for systemic anticoagulation. A multi-disciplinary team with a skilled echocardiographer is crucial for the successful implantation of these devices. 2D and 3D TEE imaging is critical for determining appropriate candidates for each device in the pre-procedure setting, ensuring procedural success with real-time guidance, and

monitoring for durable results and potential complications post-procedure.

Compliance with Ethical Standards

Conflict of Interest David Altszuler, Alan F. Vainrib, Daniel G. Bamira, and Ricardo J. Benenstein declare that they have no conflict of interest.

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Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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