The Role of Multimodality Imaging in Percutaneous Left Atrial Appendage Suture Ligation with the LARIAT Device

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Atrial fibrillation (AF), the most common cardiac arrhythmia, is a significant cause of embolic stroke. Although systemic anticoagulation is the primary strategy for preventing the thromboembolic complications of AF, anticoagulants carry major bleeding risks, and many patients have contraindications to their use. Because thromboembolism typically arises from a clot in the left atrial appendage (LAA), local therapeutic alternatives to systemic anticoagulation involving surgical or percutaneous exclusion of the LAA have been developed. Surgical exclusion of the LAA is typically performed only as an adjunct to other cardiac surgeries, thus limiting the number of eligible patients. Furthermore, surgical exclusion of the LAA is frequently incomplete, and thromboembolism may still occur. Percutaneous LAA exclusion includes two approaches: transseptal delivery of an occlusion device to the LAA and epicardial suture ligation of the LAA, the LARIAT procedure. In the LARIAT procedure, a pretied snare is placed around the epicardial surface of the LAA orifice via pericardial access. Proper snare placement is achieved with epicardial and endocardial magnet-tipped guidewires. The endocardial wire is advanced transvenously to the LAA apex after transseptal puncture. The epicardial wire, introduced into the pericardial space, achieves end-to-end union with the endocardial wire at the LAA apex. The snare is then placed over the LAA, tightened, and sutured. On the basis of early clinical experience, the LARIAT procedure has a high success rate of LAA exclusion with low risk for complications. The authors describe the indispensable role of real-time transesophageal echocardiography in the guidance of LAA epicardial suture ligation with the LARIAT device. (J Am Soc Echocardiogr 2014;27:699-708.)

Keywords: Transesophageal echocardiography, 3D, Left atrial appendage exclusion, LARIAT device, Atrial fibrillation

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia in the world and is estimated to affect >3 million people in the United States.[1] The increased prevalence of AF with age, combined with an aging population, creates a projected increased incidence of AF in the United States to 7.56 million by 2050.[1]

Systemic thromboembolism is the major complication of both valvular and nonvalvular AF. The left atrial appendage (LAA) is the most common site of thrombus formation, accounting for 91% of left heart thrombi in patients with nonrheumatic AF and 57% of thrombi in patients with rheumatic AF.[2]

Systemic anticoagulation is the primary means of preventing thromboembolism in patients with AF. Antiplatelet agents are an alternative to systemic anticoagulation but with inferior efficacy. Adequate anticoagulation with oral warfarin has been demonstrated to cut the risk for stroke and systemic embolism by 67% compared with placebo[3] and by 45% compared with aspirin.[4] Newer anticoagulants (such as dabigatran, apixaban, and rivaroxaban) have been shown to be at least noninferior to warfarin.[5-7]

However, all anticoagulants have significant bleeding risk; the risk for major bleeding (generally defined as a reduction in the hemoglobin level of ≥20 g/L, transfusion of ≥2 U of packed red cells, or symptomatic bleeding occurring at a critical site or resulting in death) with either warfarin or newer agents is estimated at 1.4% to >3% per year.[5-8] Because AF-associated systemic thromboembolism typically arises from a clot confined to the LAA, local therapeutic alternatives to systemic antithrombotic and antiplatelet therapy have been developed. These alternatives include either surgical or percutaneous exclusion of the LAA from the systemic circulation.

Surgical techniques of LAA exclusion have included ligation, clipping, stapling, and amputation.[9-11] However, only a small number of patients with AF are eligible for these procedures because surgical LAA exclusion is typically performed only as an adjunct to other cardiac operative interventions.

Although prophylactic exclusion of the LAA in patients undergoing mitral valve surgery and/or maze procedure is recommended to reduce systemic thromboembolic events,[12] such exclusion is frequently incomplete, and residual communication with the

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The authors have no conflicts of interests to disclose.

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0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2014.04.014

Abbreviations
AF = Atrial fibrillation
CT = Computed tomographic
LAA = Left atrial appendage
TEE = Transesophageal echocardiographic
3D = Three-dimensional
2D = Two-dimensional

body of the left atrium due to incomplete LAA exclusion can paradoxically increase the risk for thrombus formation in the LAA.[13]

Percutaneous alternatives to surgical LAA exclusion include transseptal delivery of various LAA occlusion devices, such as the PLAATO (eV3, Plymouth, MN), Watchman (Boston Scientific, Maple Grove, MN) or Amplatzer Cardiac Plug (St. Jude Medical, Minneapolis, MN),[14-16] and transpericardial suture ligation of the LAA using the LARIAT device (Sentre-HEART, Palo Alto, CA).[17-20]

Outcomes data are most numerous for the Watchman device, which was found to be noninferior to chronic warfarin therapy in a randomized trial.[16] However, Watchman device implantation was associated with procedural complications, including pericardial effusion, device embolization, and procedure-related stroke.[21] Furthermore, after device implantation, patients typically require warfarin therapy for 45 days and dual-antiplatelet therapy (with aspirin and clopidogrel) for 6 months to prevent clot formation during device endothelialization.[16]

In contrast, percutaneous LAA closure with the LARIAT device, which includes an epicardial suture, does not leave any device in contact with the bloodstream and thus does not typically require postprocedural warfarin therapy.[18,22] The LARIAT procedure, which may also be referred to as the permanent ligation, approximation, closure, and exclusion procedure, is an option in patients with contraindications or intolerance to anticoagulation. On the basis of short-term observational data,[17-20] the LARIAT procedure is feasible, but proof of its long-term efficacy in a randomized trial is still lacking.

We emphasize that LARIAT Suture Delivery Device is not specifically approved for LAA ligation and that there is a paucity of outcomes data. Its approved indication is defined as facilitating suture placement and knot tying for use in surgical applications in which soft tissue is being approximated and/or ligated with a pretied polyester suture. However, the LARIAT procedure has entered clinical practice.

In this review, we discuss the crucial role of echocardiography (including real-time three-dimensional [3D] transesophageal echocardiographic [TEE] imaging) in periprocedural guidance of the LARIAT procedure and the relationship of echocardiography to other imaging modalities, such as fluoroscopy and computed tomographic (CT) imaging.

CLINICAL EXPERIENCE WITH THE LARIAT PROCEDURE

Thus far, there are reports of three observational studies with the LARIAT device.[17-19] Patients were enrolled in these studies if they had AF, had $CHADS_2$ scores of ≥ 1 or ≥ 2, and demonstrated contraindications to or failure of anticoagulation. Patients were excluded if they had prior cardiac surgery, a myocardial infarction within 3 months, embolic events within 30 days, or histories of pericarditis. Additional exclusion criteria were related to LAA anatomy: superior orientation of the LAA with the LAA apex positioned behind the main pulmonary artery and/or LAA width > 40 mm.

In an initial nonrandomized single-center trial, LAA ligation with the LARIAT device was successful in 96% of patients (85 of 89) when assessed by TEE imaging immediately after the procedure and in 98% at 1 year of the 65 patients who completed 1-year TEE follow-up.[17] Another trial reported successful LAA exclusion in all 20 patients who underwent the procedure.[18] A third study had an acute procedural success rate of 92.6% (25 of 27 subjects); the LAA remained excluded in all 22 patients who completed 45-day TEE follow-up.[19] Although these are encouraging results, long-term data on the complete LAA closure rate by the LARIAT procedure in a larger group of patients are still unavailable.

These observational studies showed low rates of periprocedural complications, the most common being pericarditis[17-19] and pericardial effusion.[17,18] Two cases of intraprocedural right ventricular perforation[17,18] and one of LAA perforation[19] were also reported in these studies.

THE LARIAT PROCEDURE IN A NUTSHELL

The LARIAT procedure consists of two parts based on access: (1) an endocardial (transvenous) portion and (2) an epicardial (transpericardial) portion. The endocardial portion entails transvenous access (typically through a femoral vein) to the right atrium with subsequent transseptal puncture and delivery of the endocardial magnet-tipped wire across the interatrial septum into the tip of the LAA.

The epicardial portion involves transthoracic pericardial access in the subxiphoid region and delivery of the epicardial magnet-tipped wire to the apex of the LAA to create an end-to-end magnetic union with the endocardial wire. There is no direct physical contact between the two wires because there is interposition of the LAA wall between them. The procedure ends with the placement of a pretied epicardial suture over the ostium of the LAA using the LARIAT device. It is important to emphasize that the LAA ostium is here defined from the procedural point of view and refers to the location of LAA ligation by the LARIAT procedure. It is similar to the location of the LAA orifice occluded by percutaneous closure devices such as the Watchman. This orifice is more distal than the true anatomic LAA orifice, because the area of the ligament of Marshall (the "Coumadin ridge") typically cannot be ligated. The procedural LAA orifice is located at the level of the left circumflex artery and the coronary sinus.

In animal studies, postmortem histologic examination revealed complete endothelialization of the sutured LAA orifice as early as 7 days after the procedure.[23]

ROLE OF MULTIMODALITY IMAGING INCLUDING TWO-DIMENSIONAL AND 3D TEE DURING THE LARIAT PROCEDURE

The preparations and stages of the procedure have been previously described.[17-19] Briefly, after clinical evaluation, potential candidates for the LARIAT procedure undergo contrast-enhanced chest CT imaging. If eligible, they then undergo the LARIAT procedure under fluoroscopic and TEE guidance.

CT scanning is used to ascertain the LAA anatomy, including its orientation and orifice size (Figure 1, Video 1; available at www.onlinejase.com). Unfavorable LAA anatomy (Figure 2, Video 2; available at www.onlinejase.com) includes a large LAA size (diameter >

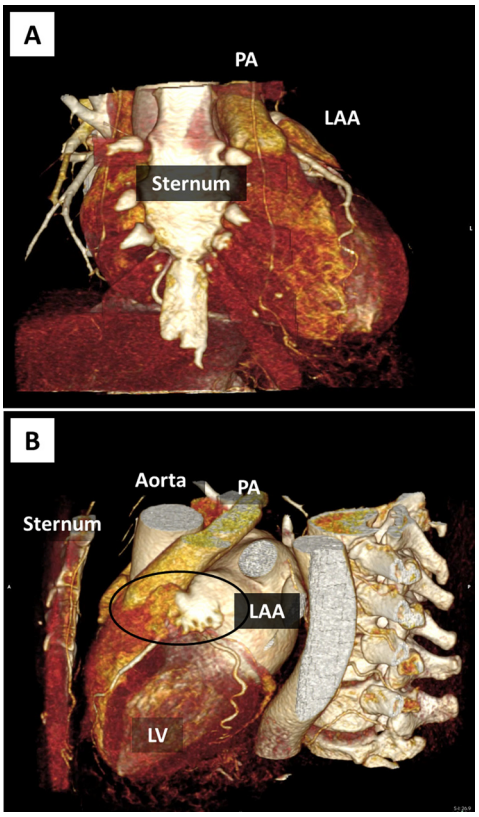

Figure 1 CT imaging of favorable LAA anatomy. **(A)** Anteroposterior view of the chest with the sternum in the foreground. The LAA is lateral to the main pulmonary artery (PA). This LAA anatomy is typically favorable for the LARIAT procedure. **(B)** Corresponding lateral view with the LAA in the foreground. *LV*, Left ventricle.

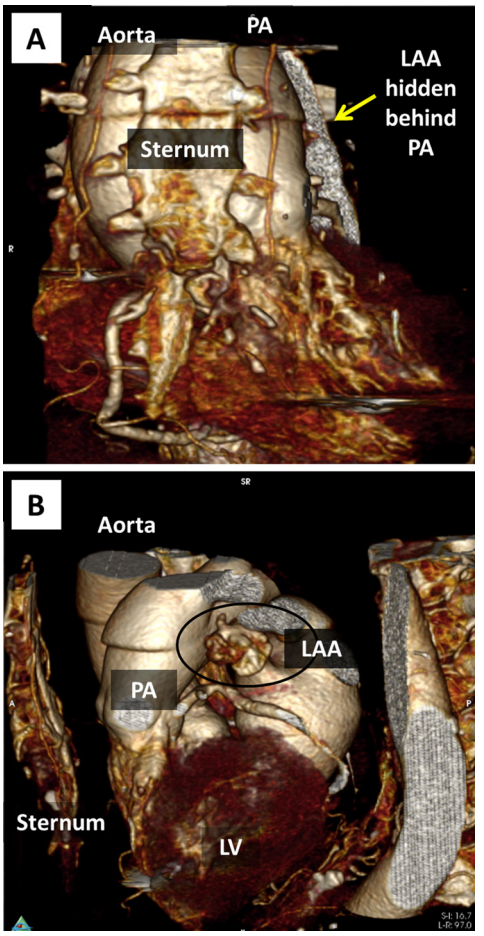

Figure 2 CT imaging of unfavorable LAA anatomy. **(A)** Anteroposterior view of the chest with the sternum in the foreground. The LAA is hidden behind the main pulmonary artery (PA). This LAA anatomy is typically unfavorable for the LARIAT procedure. **(B)** Corresponding lateral view with the LAA in the foreground and posterior to the PA. *LV*, Left ventricle.

40 mm) and a superiorly oriented LAA with the apex positioned behind the pulmonary trunk.[17] Such LAA anatomy may make passage of the LARIAT snare over the LAA difficult.

In addition to standard cross-sectional two-dimensional (2D) imaging, 3D CT reconstruction is performed to provide a more detailed view of LAA morphology and its relationship to surrounding structures. This CT reconstruction will also help in guiding subsequent pericardial access during the LARIAT procedure; in particular, 3D reconstructions display the relationship between the sternum and the myocardium. This information will allow the clinician to determine how steeply and how far the pericardial needle should be inserted.[17]

Once a patient is deemed eligible, the LARIAT procedure is typically done under general anesthesia to minimize patient discomfort. In a sterile fashion, the subxiphoid region (for epicardial access) and the femoral vein region (for transseptal access) are prepped and draped.

TEE guidance in conjunction with fluoroscopy is essential for successful completion of the LARIAT procedure, as well as for monitoring for any periprocedural complications. Any modern ultrasound system with a 2D TEE multiplane probe may be used to monitor the LARIAT procedure. If available, 3D TEE imaging provides additional details of LAA anatomy and enhances visualization of wires, balloons, and catheters.[24] Three-dimensional TEE imaging may overcome many of the limitations of 2D TEE imaging related to the tomographic nature of 2D imaging: intracardiac wires, balloons, and catheters move in a 3D space, and frequently their courses are outside 2D imaging planes. In general, compared with 2D TEE imaging, 3D TEE imaging provides better visualization of the intracardiac course of the procedural hardware, particularly the catheter and wire tips.

For 3D TEE imaging, a commercially available ultrasound system using a matrix-array 3D TEE probe may be used. Of the 3D TEE imaging modalities, biplane and 3D zoom imaging appear the most helpful. Biplane imaging is particularly useful during and may enhance the safety of the transseptal puncture compared with 2D TEE. Three-dimensional zoom imaging provides intuitive en face views of cardiac structures, facilitating procedural guidance aside from transseptal puncture.[25] We have not found that full-volume and so-called live 3D imaging are essential for LARIAT procedural guidance.

Examination of LAA Anatomy

TEE imaging is used to confirm the findings of the preprocedural CT scan with respect to LAA orifice diameter, LAA apex orientation, and

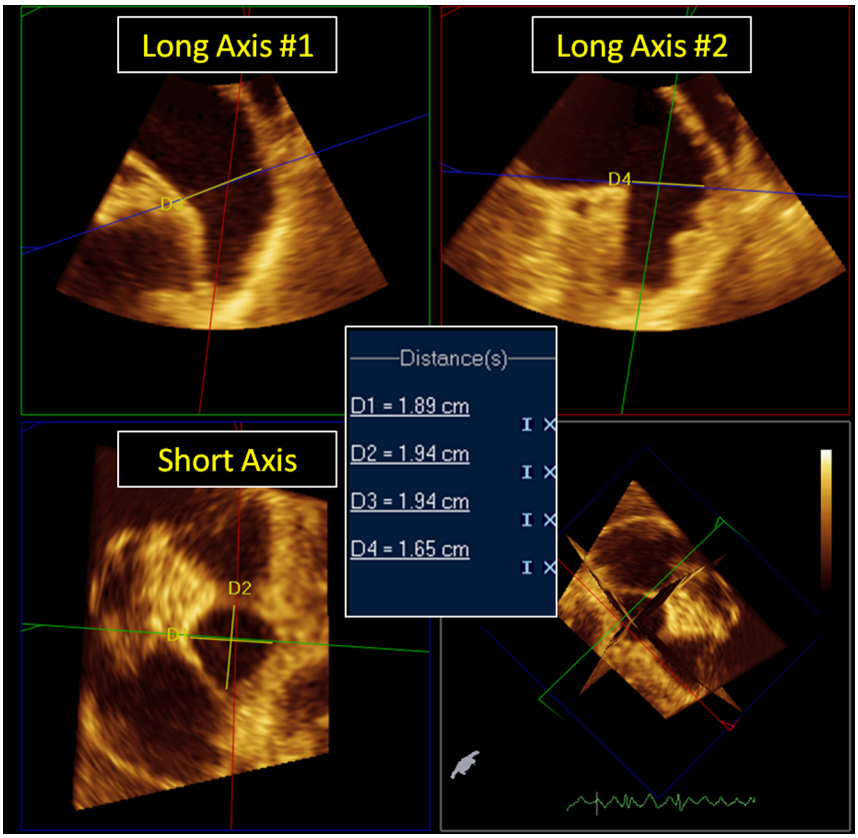

Figure 3 Three-dimensional TEE multiplane reconstruction of LAA before LARIAT procedure. Multiplane reconstruction allows simultaneous visualization of the LAA in three orthogonal planes: two in long axis and one in short axis. This allows precise measurements of the ostial size of the LAA. The LAA ostium is here defined from the interventional perspective as the location of ligation; the location of this ostium may differ from the anatomic LAA ostium.

the number of LAA lobes. TEE imaging is the modality of choice for visualization of LAA thrombi, as previously described.[26] As previously noted, the following are the current exclusion criteria for the LARIAT procedure: LAA width > 40 mm, superiorly oriented LAA with the apex behind the pulmonary trunk, and LAA thrombus. All 2D and 3D echocardiographic LAA measurements are done at ventricular end-systole.[27,28]

On 2D TEE imaging, the LAA should be imaged at multiple angles, typically 0°, 45°, 90°, and 135°. Measurements of the LAA orifice are performed at all imaging angles to determine the maximum diameter. Because of the tomographic nature of 2D imaging, one cannot be certain that 2D TEE orifice diameter measurements are done in the same plane. This can be overcome by 3D TEE imaging, either by multiplane reconstruction or using the en face 3D zoom technique. Using the multiplane reconstruction mode (Figure 3), the two long axes of the LAA are aligned to visualize the short-axis plane of the LAA, in which precise measurements of LAA diameters are performed.[27,28]

Compared to multiplane reconstruction, the 3D TEE zoom technique provides a simpler way to directly visualize the short-axis en face view of the LAA. Images may be cropped along the x, y, and z axes to eliminate nonrelevant structures and more clearly visualize the LAA.[29,30] Details of the 3D zoom techniques are provided elsewhere.[27,28] With the newest generation of 3D TEE software, LAA diameter can be measured online from en face images of the LAA orifice.

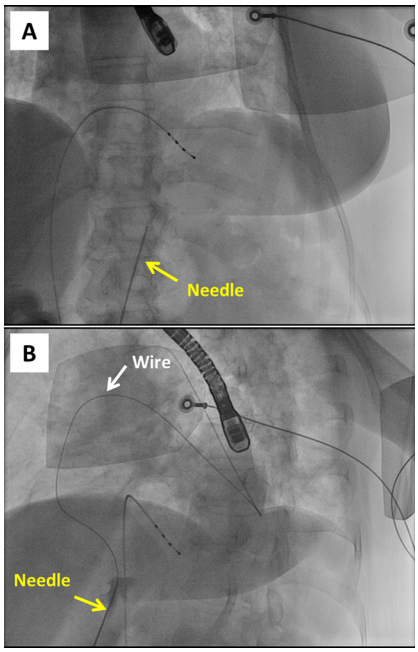

Figure 4 Fluoroscopic guidance of pericardial access. **(A)** Anteroposterior view demonstrates the path of the pericardial needle (*arrow*). **(B)** In the next step, a wire (*white arrow*) is introduced into the pericardial space through the needle (*yellow arrow*).

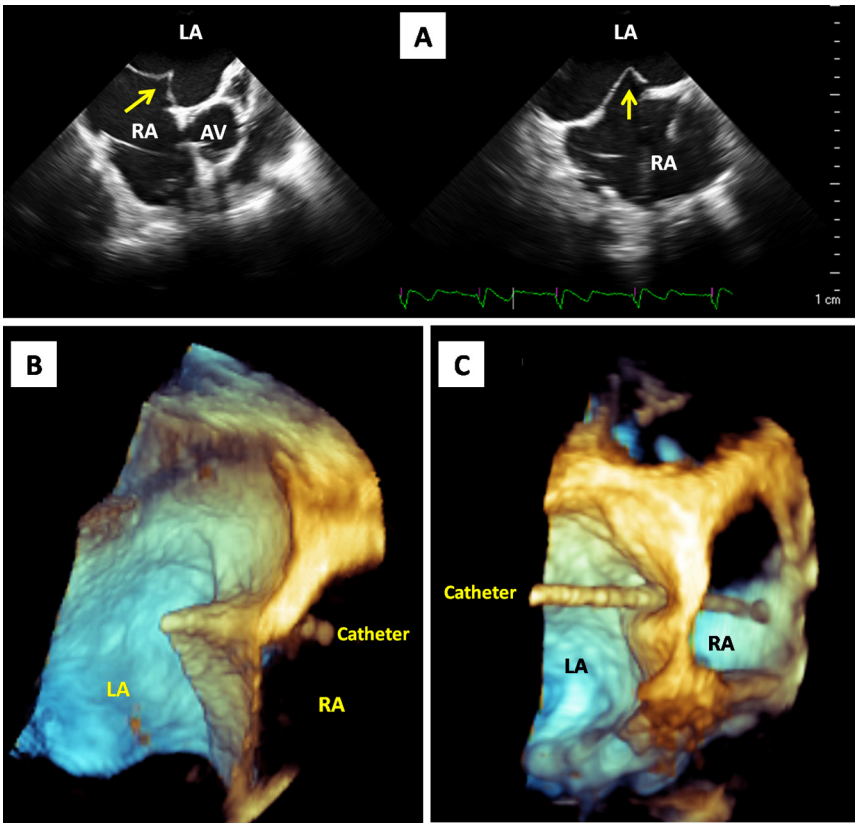

Figure 5 TEE guidance of transseptal puncture. **(A)** Biplane TEE view demonstrates proper tenting of the interatrial septum (*arrow*) before transseptal puncture. **(B,C)** Three-dimensional TEE image of the interatrial septum during transseptal puncture. In both panels, the interatrial septum is viewed from the posterior perspective. In **(B)**, a catheter is seen tenting the interatrial septum toward the left atrium (LA). In **(C)**, the transseptal puncture has been accomplished and the catheter is now in the LA. *AV*, Aortic valve; *RA*, right atrium.

Two-dimensional and 3D TEE imaging can also provide information on the shape and the area of the LAA orifice, as well as the depth of the LAA.[27,28] Interestingly, orifice shape and area are not as important for the LARIAT procedure as they are for LAA closure techniques using LAA occlusion devices such as the Watchman.

Two-dimensional imaging in multiple planes and careful cropping of 3D images also provide detailed information on the number and orientation of LAA lobes.

Pericardial Access

Pericardial access is the next step. It is achieved as previously described[31] under fluoroscopic guidance, typically using a 17-gauge Touhy epidural needle (Hakko, Nagano, Japan). The needle is inserted retrosternally in an anterolateral direction along the anterior epicardial surface of the heart and pointed toward the apex of the LAA (Figure 4A). During needle insertion, a minimal amount of radiographic contrast is injected to confirm fluoroscopically the needle's location in the pericardium versus the anterior mediastinum. A 0.035-inch wire (FindrWIRZ; SentreHEART) is then advanced through the needle into the anterior pericardial space. Fluoroscopy is again used to confirm the presence of the wire in the pericardial space (Figure 4B). This wire is left in the pericardial space while transseptal catheterization is achieved.

Transseptal Puncture

Two-dimensional and 3D TEE imaging is essential throughout the entire endocardial portion of the LARIAT procedure, including the transseptal puncture, placement of the SL1 catheter (St. Jude Medical) in the left atrium, advancement of the EndoCATH balloon catheter (SentreHEART) to the LAA orifice, and placement of the endocardial magnet-tipped wire in the LAA apex.

Details of 2D and 3D TEE monitoring of transseptal puncture have been previously provided.[32] Briefly, the left atrium is accessed after entering a peripheral vein (typically the femoral vein), catheters and other hardware are advanced into the right atrium, and a transseptal puncture using the Brockenbrough technique is then performed to bring the hardware across the interatrial septum into the left atrium.

For many years, transseptal puncture has been performed with a good safety record using the interventionalists' tactile feedback, fluoroscopy, and 2D echocardiography (such as 2D TEE imaging and intracardiac echocardiography).[33] Three-dimensional TEE imaging, particularly biplane and 3D TEE zoom imaging, may enhance both the safety of the puncture procedure and the success of the subsequent percutaneous intervention in the left heart (Figure 5).

Transseptal puncture in the posterior and inferior portion of the fossa ovalis is the preferred route because it allows the most direct

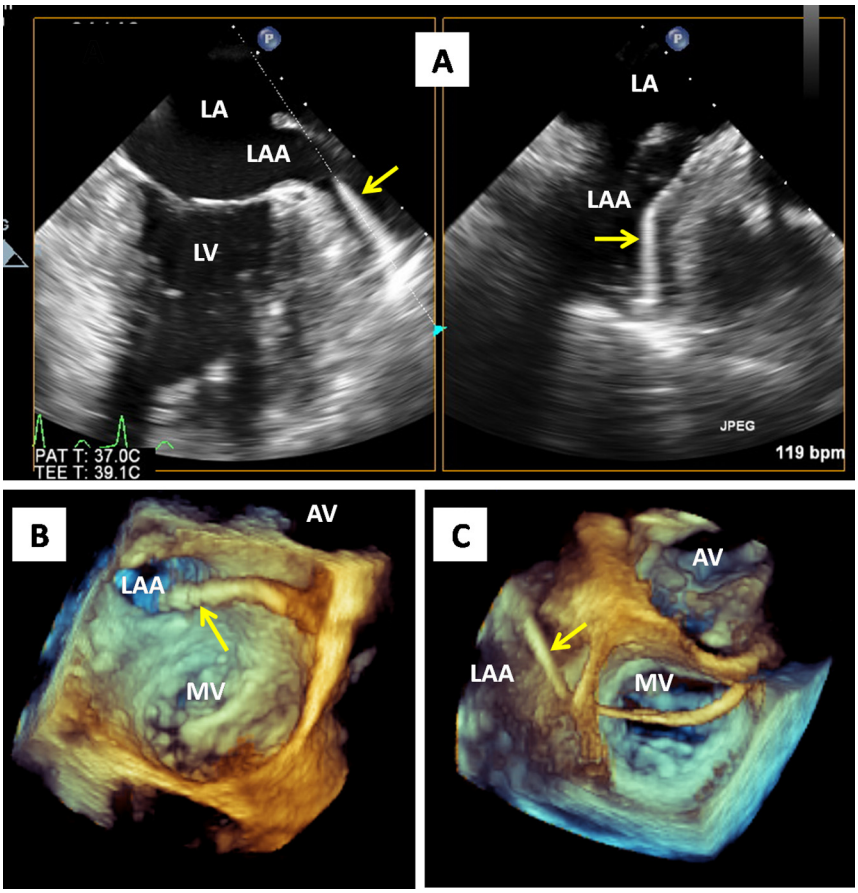

Figure 6 TEE guidance of endocardial magnet wire placement. **(A)** Biplane 3D TEE image demonstrates proper placement of the endocardial magnet wire (*arrow*) with its tip in the apex of the LAA. **(B,C)** Three-dimensional TEE zoom imaging during endocardial magnet wire deployment. In **(B)**, the catheter (*arrow*) that contains the wire is guided into the orifice of the LAA above the mitral valve (MV). In **(C)**, the wire (*arrow*) is advanced into the LAA. *AV*, Aortic valve; *LA*, left atrium; *LV*, left ventricle.

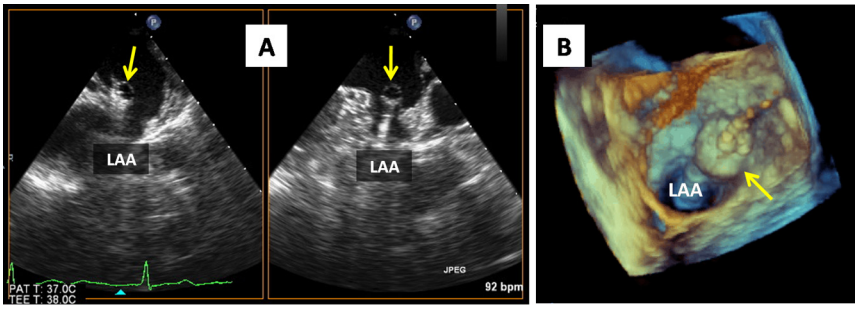

Figure 7 TEE guidance of LARIAT balloon placement. **(A)** Three-dimensional TEE biplane image demonstrates proper balloon placement (*arrow*) at the orifice of the LAA. **(B)** Three-dimensional TEE zoom image shows inflated balloon at the orifice of the LAA.

path to the LAA. However, the middle of the interatrial septum is an acceptable location.

Endocardial Portion of the LARIAT Procedure

After transseptal puncture, an 8.5-F SL1 catheter is advanced into the left atrium and directed toward the LAA. Radiographic contrast is then injected to obtain an left atrial appendagegram in the right anterior oblique position. Three-dimensional TEE imaging has the distinct advantage of visualizing the entire lengths of catheters and wires as they traverse the left atrium to reach the LAA.[34] Furthermore, 3D TEE imaging ensures that the endocardial magnet-tipped wire is placed in the LAA tip (Figure 6, Video 3; available at www.onlinejase.com).

In the next step, a 15-mm balloon-tipped catheter (EndoCATH) back-loaded with a magnet-tipped 0.025-inch guidewire

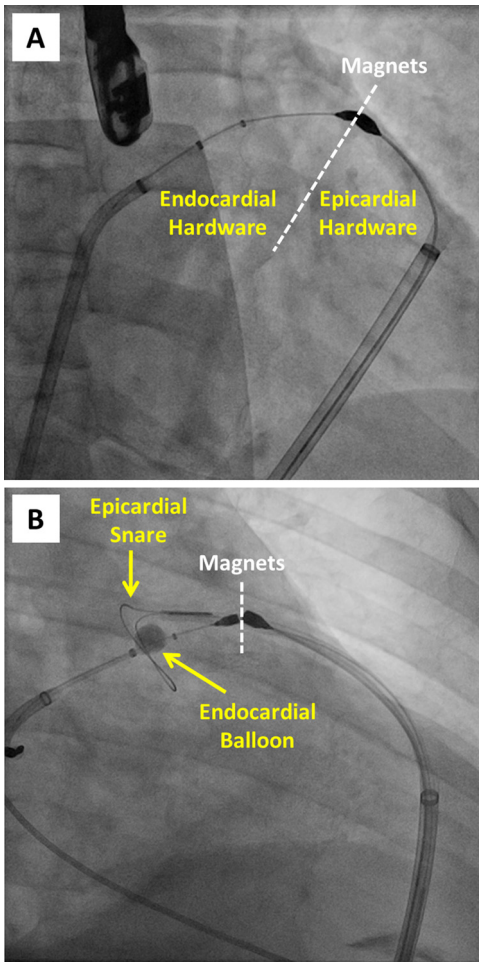

Figure 8 LARIAT procedure guidance by fluoroscopy. **(A)** The two magnet-tipped guidewires are united at the tip of the LAA. The endocardial wire, seen on the left, is situated in the LAA with its magnetic tip in the apex. The epicardial wire, seen on the right, lies along the anterior aspect of the heart with its magnetic tip on the epicardium of the LAA apex. **(B)** After end-to-end magnetic union of the magnet-tipped guidewires, the LARIAT snare is advanced epicardially over the LAA to the ostium. Radio-opaque proximal and distal markers of the endocardial balloon are observed to the left of the magnetic tip, with the proximal marker delineating the ostium of the LAA. The balloon is inflated to prevent slippage of the snare off the base of the appendage. After the snare is tightened, the endocardial balloon catheter and endocardial wire are removed from the LAA, and the epicardial suture is released from the snare and tightened, excluding the LAA from the left atrium.

(FindrWIRZ) is advanced through the SL1 catheter into the LAA under fluoroscopic and TEE guidance. The magnet wire tip is placed in the apex of the LAA and the deflated balloon at the ostium of the LAA. The balloon is then inflated with approximately 1 mL of a 1:1 mixture of normal saline and radiographic contrast. The accurate placement of the EndoCATH balloon during the LARIAT procedure is crucial, because it both delineates the ostium of the LAA for LARIAT snare placement and ensures that the suture does not slip off the LAA during tightening.[35] Two-dimensional and 3D TEE imaging ensures that the balloon is properly placed at the LAA orifice (Figure 7). The balloon is subsequently left deflated until the final steps of the LARIAT procedure.

Epicardial Portion of the LARIAT Procedure

Next, sequential dilations of the epicardial access are performed until the 14-F soft-tipped epicardial guide cannula (SentreHEART) can be advanced over the wire and into the anterior pericardial space. The 0.035-inch magnet-tipped guidewire is then inserted through the epicardial guide cannula into the pericardial space and adjusted so that the magnetic tip of the epicardial wire achieves magnetic union with the magnetic end of the endocardial guidewire (Figure 8A, Video 4; available at www.onlinejase.com). Through sequential cropping, 3D TEE imaging may also verify the magnetic union between the endocardial and epicardial magnet-tipped wires.[24]

Once the magnets are attached, the 12-F LARIAT Suture Delivery Device is introduced into the pericardial space through the guide cannula. The LARIAT device consists of a pretied surgical suture mounted on a snare and a suture cutter. The snare is positioned over the epicardial surface of the LAA (Figure 8B). To confirm that the snare is located at the ostium of the LAA, the intracardiac 15-mm EndoCATH balloon is again inflated with approximately 1 mL of a 1:1 mixture of normal saline and radiographic contrast.

Completion of the LARIAT Procedure

A radio-opaque marker on the distal tip of the LARIAT is then aligned with the proximal marker of the inflated EndoCATH balloon positioned at the ostium of the LAA. After once again confirming the location of the balloon at the LAA ostium by TEE imaging, the LARIAT snare is closed while the balloon is still inflated.

Two-dimensional and 3D TEE imaging with color Doppler (along with left atrial angiography) is used here to confirm the lack of a significant residual communication between the left atrium and the LAA. A small degree of color Doppler flow may normally be seen along the EndoCATH, which is still located in the LAA at this initial stage of LAA closure (Figure 9, Videos 5–7; available at www.onlinejase.com).

The EndoCATH balloon is then deflated; the balloon and endocardial magnet-tipped wire are then withdrawn from the LAA. The preloaded surgical suture is then released from the snare and tightened. At this point, the interventionalist waits for 5 min and then tightens the suture a second time to ensure maximum closure. The LARIAT snare is then retracted from the pericardial space. On the endocardial side, the balloon catheter–magnet wire assembly is retracted through the SL1 catheter. Finally, the epicardial suture is cut near the LAA ostium by the suture cutter. Successful exclusion of the LAA is defined as an LAA Doppler flow width between the LAA and LA of <5 mm, although typically there is no Doppler flow (Figure 10, Video 8; available at www.onlinejase.com). En face 3D TEE views of the LAA orifice with color Doppler overlay allow the precise location of a residual leak.

In the next step, on the epicardial side, the 14-F soft-tipped guide cannula is removed over the 0.035-inch epicardial guidewire and replaced with a pericardial drain. The wire is then removed. On the endocardial side, the transseptal SL1 catheter is removed from the body. TEE imaging is performed at the end of the procedure to assess for any immediate complications. The drain is kept in place for $\geq$6 hours, during which the patient remains hospitalized.

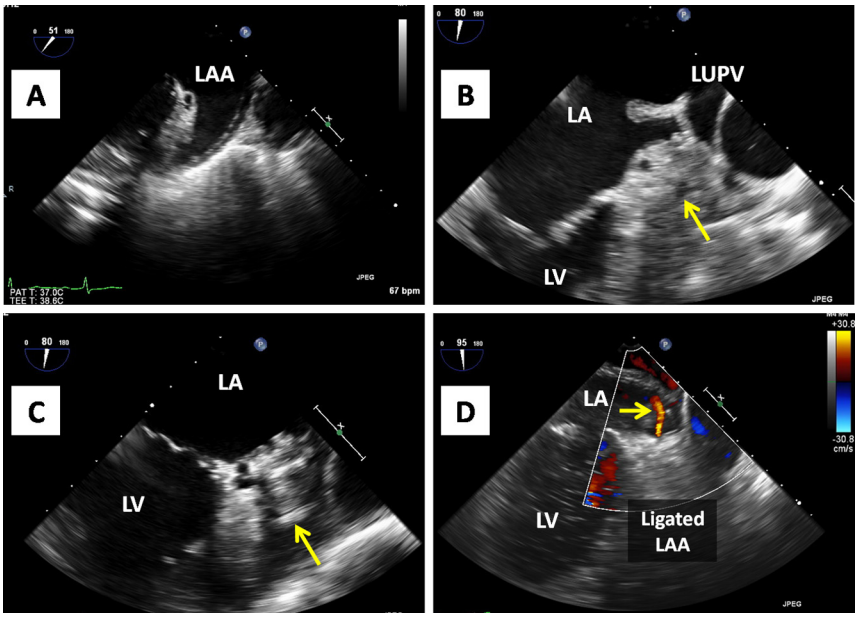

Figure 9 TEE assessment of LARIAT closure of the LAA. **(A)** Two-dimensional TEE appearance of the LAA before LARIAT closure. **(B)** Typical appearance of the LAA after LARIAT ligation. **(C)** Appearance of a ligated LAA in another patient. In this patient, the presence of a pericardial effusion outlines the ligated appendage (*arrow*). **(D)** After the LARIAT snare is deployed but before removal of the endocardial catheter from the LAA, a small degree of central leak (*arrow*) may be seen on color Doppler imaging. *LA*, Left atrium; *LV*, left ventricle; *LUPV*, left upper pulmonary vein.

During recovery, transthoracic echocardiography is performed to rule out any pericardial effusion. The pericardial drain is then removed, and the patient is discharged.

Evaluation for Possible Periprocedural Complications

Pericardial effusion is the most important complication to look for by TEE imaging during the LARIAT procedure. Standard 2D TEE imaging in multiple windows is used to diagnose a pericardial effusion. Transgastric imaging is particularly useful for visualizing pericardial effusion. Pericardial effusion arising from intraprocedural perforation of cardiac chambers such as the right ventricle or the LAA has been described.[17-19,36] Theoretically, damage to the coronary circulation may also lead to periprocedural pericardial effusion.

In two clinical series, periprocedural pericardial effusion was observed in 3.7% (one of 27) and 5% (one of 20) of patients.[18,19] Right ventricular perforation was noted in two of the three series, occurring in 5% of patients (one of 20) in one study and 1.1% of patients (one of 89) in another study, the latter resulting in an aborted procedure.[17,18] In one study, LAA perforation requiring pericardial drainage and blood transfusions occurred in 3.7% of patients (one of 27).[19]

In some instances, the presence of a significant pericardial effusion may necessitate aborting the LARIAT procedure. However, when the pericardial effusion results from LAA perforation, completion of LAA ligation using the LARIAT system may be the best course of action. A recent case report specifically addressed this issue.[36] During the procedure, a left atrial appendagegram revealed leakage into the pericardial space consistent with LAA perforation, which likely occurred while placing the magnet-tipped wire into the LAA or from tension imposed on the LAA wall with the magnet wires attached. The snare was subsequently closed as planned to exclude the LAA, which also treated the LAA perforation.

CONCLUSIONS

On the basis of early clinical experience, the LARIAT procedure leads to successful exclusion of the LAA from the systemic circulation in most patients. This may reduce the risk for systemic thromboembolism associated with AF. The advantages of the LARIAT procedure over percutaneously implanted exclusion devices (such as the Watchman) are that there is no risk for device embolization and because no device is left in contact with the bloodstream, there is no need for postprocedural warfarin. Pericardial effusion and pericarditis are major but uncommon complications of the LARIAT procedure on the basis of short-term follow-up studies.

Two-dimensional and 3D TEE imaging is used in conjunction with fluoroscopy throughout the procedure. TEE imaging aids in transseptal puncture, correct placement of the intracardiac balloon and catheters, confirmation of complete LAA closure after ligation, and monitoring of periprocedural complications. Real-time 3D TEE imaging may provide a more comprehensive preprocedural assessment of the anatomy of the LAA and better intraprocedural visualization of wires, balloons, and catheters. TEE imaging is indispensible in the successful performance of the LARIAT procedure.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.echo.2014.04.014.

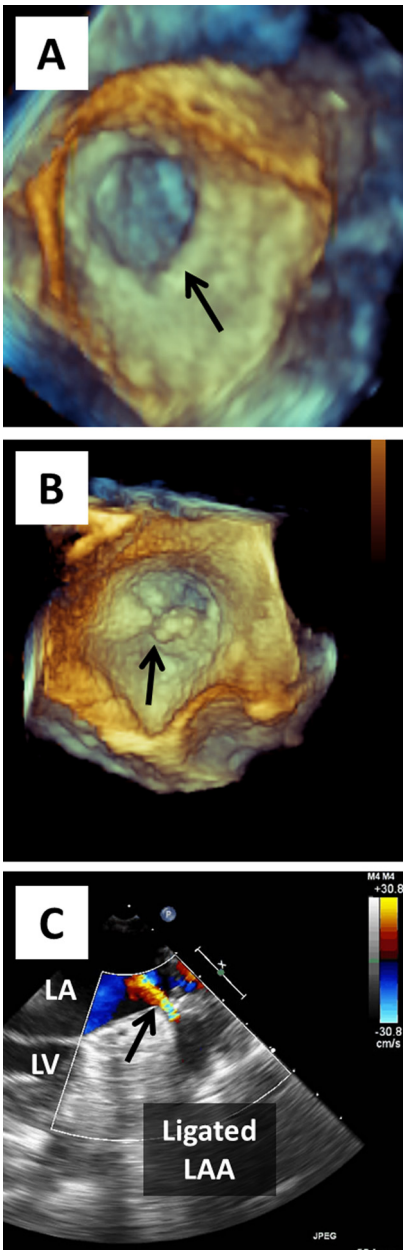

Figure 10 Three-dimensional TEE appearance of LAA at baseline and after ligation. Three-dimensional TEE zoom imaging demonstrates the en face view of the LAA orifice seen from the left atrial perspective. **(A)** At baseline, there is a widely patent orifice of the LAA (*arrow*). **(B)** After completion of the LARIAT suture ligation, the LAA orifice is completely closed. The arrow points to the location of the suture. Note the "bowtie" appearance of the ligated LAA orifice. **(C)** After completion of the LARIAT procedure, there are typically no residual leaks between the left atrium (LA) and LAA. If there is a residual leak, it is typically solitary and central, as shown in this panel (*arrow*). *LV*, Left ventricle.

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