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Roles of real-time three-dimensional transesophageal echocardiography in peri-operation of transcatheter left atrial appendage closure

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Abstract

Left atrial appendage (LAA) closure is a new treatment option for the prevention of stroke in patients with nonvalvular atrial fibrillation (AF). Conventional 2-dimensional transesophageal echocardiography (2D TEE) has some limitations in the imaging assessment of LAA closure. Real-time 3-dimensional transesophageal echocardiography (RT-3D TEE) allows for detailed morphologic assessment of the LAA. In this study, we aim to determine the clinical values of RT-3D TEE in the periprocedure of LAA closure.

Thirty-eight persistent or paroxysmal AF patients with indications for LAA closure were enrolled in this study. RT-3D TEE full volume data of the LAA were recorded before operation to evaluate the anatomic feature, the landing zone dimension, and the depth of the LAA. On this basis, selection of LAA closure device was carried out. During the procedure, RT-3D TEE was applied to guide the interatrial septal puncture, device operation, and evaluate the occlusion effects. The patients were follow-up 1 month and 3 months postclosure.

Twenty-eight (73.7%) patients with AF received placement of LAA occlusion device under RT-3D TEE. Eleven cases with single-lobe LAAs were identified using RT-3D TEE, among which 4 showed limited depth. Seventeen cases showed bilobed or multilobed LAA. Seven cases received LAA closure using Lefort and 21 using LAmbre based on the 3D TEE and radiography. The landing zone dimension of the LAA measured by RT-3D TEE Flexi Slice mode was better correlated with the device size used for occlusion ($r = 0.90$) than 2D TEE ($r = 0.88$). The interatial septal puncture, the exchange of the sheath, as well as the release of the device were executed under the guidance of RT-3D TEE during the procedure. The average number of closure devices utilized for optimal plugging was (1.11 ± 0.31). There were no clinically unacceptable residual shunts, pericardial effusion, or tamponade right after occlusion. All the patients had the device well-seated and no evidence of closure related complications in the follow-up.

Assessment of LAA morphology by RT-3D TEE contributes to the decision of device selection for the closure. 3D TEE is a reliable imaging modality to guide device operation and assess on-site closure.

Abbreviations: AF = atrial fibrillation, 2D TEE = 2-dimensional transesophageal echocardiography, RT-3D TEE = real-time 3-dimensional transesophageal echocardiography, LAA = left atrial appendage, TTE = transthoracic echocardiography, LVEF = left ventricular ejection fraction.

Keywords: atrial fibrillation, left atrial appendage closure, real-time 3-dimensional echocardiography

1. Introduction

Thrombosis-associated stroke is a severe complication of atrial fibrillation (AF) causing substantial mortality and morbidity, especially in the aged population.[1] Over 90% cardiogenic emboli were identified from the left atrial appendage (LAA) in patients with nonvalvular AF.[2] Percutaneous LAA transcatheter occlusion has been considered as a new treatment option for the management of stroke in the patients with contraindications to Warfarin.[3,4] Up to now, extensive studies have been focused on the application of different percutaneous LAA closure devices, which confirm interventional therapy can effectively prevent the cerebral embolic events caused by AF with similar benefits of Warfarin.[5–7]

The LAA closure is highly depending on the accurate determination of anatomical structure. Two-dimensional transesophageal echocardiography (2D TEE) has been commonly utilized in the interventional therapy as a perioperative imaging modality since it could evaluate the morphology of LAA in multiple views. However, the diagnostic information is limited in some patients with poor tolerance to the semi-invasive TEE.

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Recently, the real-time 3-dimensional transesophageal echocardiography (RT-3D TEE) has been shown to be a feasible and accurate technique to further determine the lesions and adjacent structures without causing any interference to the surgical fields and procedures. It can provide more detailed information for the LAA through reconstruction and may have certain advantages than 2D TEE in transcatheter LAA closure.[8,9]

In this study, we aimed to discuss the clinical value of RT-3D TEE in transcatheter LAA closure. Besides, the indications of 2 LAA closure devices including LAmbre and Lefort were discussed. Our study contributed to the application of RT-3D TEE for the nonvalvular AF patients receiving LAA closure device.

2. Methods

2.1. Patients

Thirty-eight persistent or paroxysmal AF patients with indications for LAA closure admitted to our hospital from January 2014 to April 2015 were enrolled in this study. The inclusion criteria for LAA closure were as follows: (i) those with nonvalvular atrial fibrillation; (ii) those with a CHA2DS2-VASc score of ≥ 2 (1 point was assigned for the presence of congestive heart failure, high blood pressure, aged ≥ 65 years, and diabetes; and 2 points for aged ≥ 75 years, a history of stroke, or transient ischemic attack); and (iii) those with side effects after warfarin, showing contraindications to warfarin therapy or anticoagulant failure. The exclusion criteria were as follows: (i) with heart failure level of New York Heart Association IV or a left ventricular ejection fraction (LVEF) of less than 40%; (ii) presence of thrombus or spontaneous echo contrast inside the left atrium or the left atrial appendage revealing by TEE; (iii) showing myocardial infarction or acute myocardial infarction within 3 months; (iv) unable to receive interventional therapy due to vascular abnormalities or deformities; and (v) those with active hemorrhage or disorder in blood coagulation. Before LAA closure, all the patients were well informed of the potential risks and benefits, and signed the informed consent. The study protocols were approved by the Ethical Committee of Renmin Hospital of Wuhan University.

2.2. Preoperative LAA morphology assessment via 2D TEE and 3D TEE

Transthoracic echocardiography (TTE) and TEE was performed on all the 38 patients using commercially available ultrasound diagnostic system (Vivid E9, GE Healthcare, WI) by experienced investigators. For the TTE, a transthoracic 1.5–4.5 MHz probe (M5S) was used to determine the valvular lesions and LVEF.

The patients were required to be in a fasting status at least 10 hours before TEE. Ten minutes after topical anesthesia to the pharyngeal mucosal, a 6VT-D 3-dimensional transesophageal probe (5 MHz, frame rate: 60–80 fps) was used to require the 2D and 3D images. On this basis, the left atrium, interatrial septum, and LAA were subsequently evaluated. The baseline levels of mitral regurgitation, pericardial effusion, and left superior pulmonary venous flow were recorded. Using the 2D TEE mode, consecutive gray-scale images during the cardiac cycles at the 0°, 45°, 90°, and 135° planes were recorded to assess the dimensions of LAA. The largest dimension was considered as the final result of 2D TEE measurement. Once the LAA was clearly displayed at 90°, the 3D mode was switched on to tailor LAA into a sampling box by pressing the "zoom" button. Subsequently, the full volume data for the LAA over the 5 continuous cardiac cycles were recorded under single beat mode. The EchoPac workstation (GE Healthcare, WI) was used for the 3D data analysis.

The 3D Flexi Slice mode, similar with CT multiplanar reconstruction, was applied to clearly display the cross-section of the LAA orifice. First, the yellow line was fixed using the Flexi Slice mode, and then the green and white lines were adjusted until the cross section of LAA orifice was clearly displayed. The left circumflex of the coronary artery was chosen as the anatomic landmark to measure the largest dimension of LAA landing zone based on the 2D TEE and 3D TEE images. The dimension of landing zone was determined at a position about 1 to 2 cm beneath the left superior pulmonary vein ridge. The depth of LAA was defined as the distance between the orifice to the apex of the atrial appendage (Fig. 1). Second, the LAA orifice was reconstructed using RT-3D TEE, to determine the number and morphology of orifice, trabeculations, as well as the distance between the trabecula and the orifice. The morphologic characters of the LAAs were recorded as single-lobe, bi-lobe,

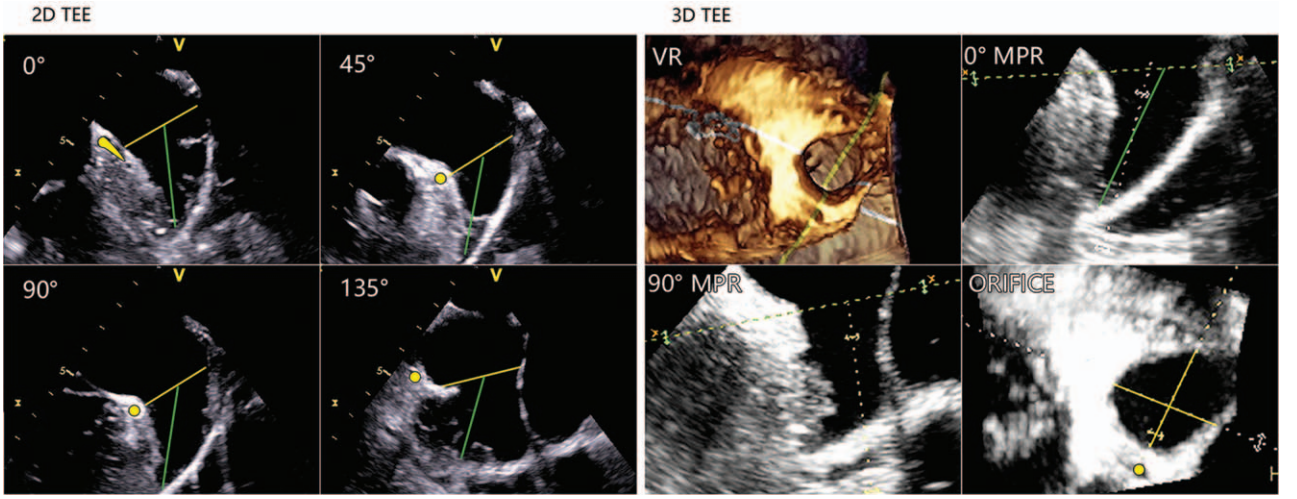

Figure 1. Measurement of LAA ostial dimensions using 2D (left panel) and 3D flexi slice (right panel). The LAA orifice was completely displayed as a circle instead of a single-plane measurement via 2D TEE. Yellow line: ostial dimension; green line: LAA depth. The yellow dots or raindrops in the left panel represented the left circumflex coronary artery. LAA = left atrial appendage, 2D TEE = two-dimensional transesophageal echocardiography.

and multilobe according to the definition as an outpouching of the LAA with a width and length of ≥1 cm[10] based on the 2D TEE and 3D TEE.[11] Patients with aberrant interatrial septum, thrombus, or a spontaneous echo contrast within the LAA were excluded.

2.3. Cardiac CT measurement of the LAA

The cardiac CT images of patients received catheter-based LAA closure were collected and analyzed in order to measure the size of the orifice and the depth of the LAAs. CT images were acquired with retrospect ECG gating using a 64-Multidetector CT system (LightSpeed VCT, GE Healthcare, VA). The tube voltage was set to 120 kV, and the current was 300 to 650 mA. The thickness of the scanning layer was 5 mm, and the reconstruction thickness was 0.625 mm. The 75% phase of the R-R interval throughout the cardiac cycle was exported to GE ADW 4.6 workstation for the analysis. The maximal LAA orifice and the depth were measured based on horizontal, coronal, and sagittal sections.

2.4. Selection of LAA closure devices

Two types of LAA closure devices were used in this study, including the LAmbre (LifeTech Technology Ltd., Shenzhen, China) and Lefort (Shape Memory Alloy Co., Ltd, Shanghai, China) (Fig. 2).

The LAmbre device is made of nickel–titanium alloy and consists of an occlusion umbrella (auricular side) and sealing disk (atrial side). The occlusion umbrella could adhere to the LAA via the 8 hooks on its surface, and the surface was covered by a polyester synthetic fiber membrane to occlude the blood flow. Currently, 2 types of LAmbre devices are commercially available including the standard type and the special type. The selection of device was based on the morphologic characteristics of LAA revealed by TEE and x-ray. To be exact, the special type was used for non single-lobed appendages with large trabeculations and shallow inner spaces, whereas the standard type was suitable for most of LAAs based on the LAmbre design.

Lefort LAA occlusion plug was designed as an umbrella-shaped device with a size of 21 mm to 33 mm consisting of nickel titanium alloy metal stent outside and the flow-barrier inside. The metal stent was covered by a polyester synthetic fiber membrane on the upper part and a protruding barbule on the lower part.

GE Innova 2100 and the Philips F10 were used for fluoroscopy during the procedures. Selective LAA radiography was utilized to observe the morphology of LAA by the interventionist. The orifice dimension and the depth of LAA were measured at a right anterior oblique of 20 to 30°. The closure device was finally selected by the interventional cardiologist together with on-site fluoroscopy and 3D TEE evaluation thereafter.

2.5. Device delivery and on-site procedural assessment

The entire atrial septum was reconstructed via RT-3D TEE. The puncture site was located at the posterior–inferior portion of the atrial septum. The position of the transport sheath in the LAA

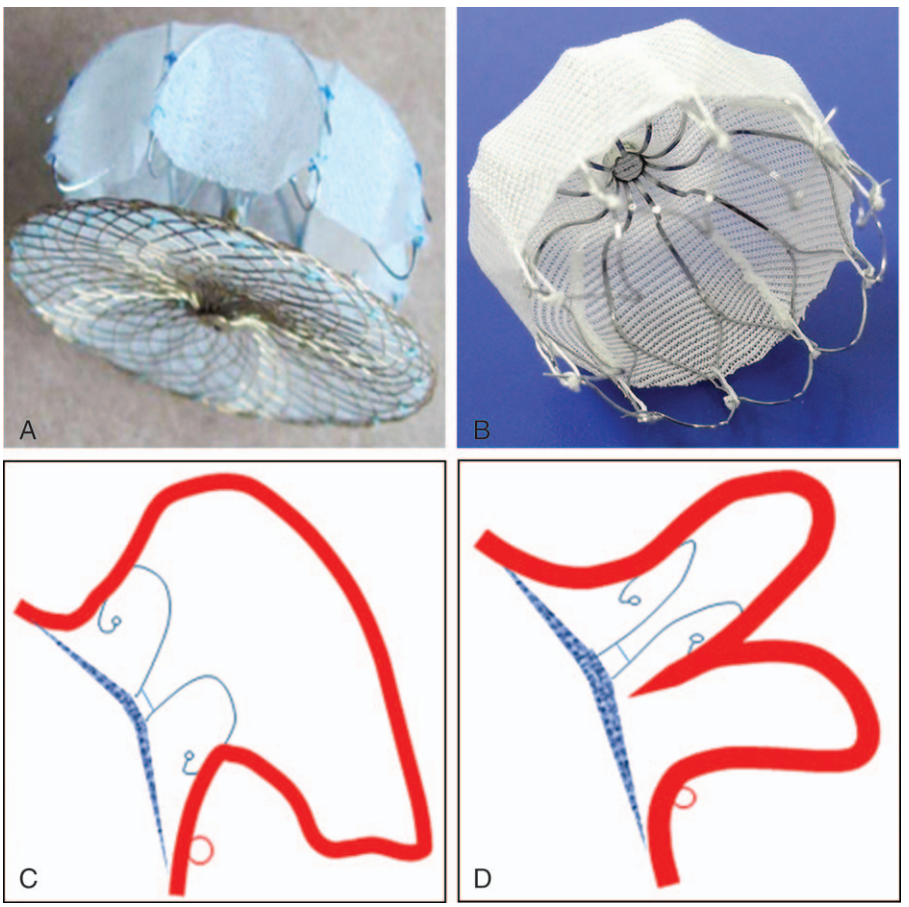

Figure 2. Schematic diagram of LAmbre LAA occlusion device (A), Lefort LAA occlusion device (B), regular type (C), and special type (D) of LAmbre LAA occlusion device. LAA = left atrial appendage.

was confirmed under the guidance of RT-3D TEE. The device was inserted and released upon reaching the appropriate position of the LAA after excluding significant leakage (>3 mm) by TEE and x-ray. Afterwards, TEE was carried out to determine the stability and shifting of the device using the tug test as previously described.[12] Meanwhile, the presence of thrombus at the left atrial surface was detected together with evaluation of function of mitral valve and pulmonary veins, LSPV dimension, and the presence of turbulent flow.

2.6. Follow-up

During the follow up, TTE was performed at month 1 and 3, whereas RT-3D TEE was performed at month 3 after the procedures. The potential adverse events such as the onset of stroke were monitored. The left atrial volume and the LVEF were evaluated. Besides, the pericardial effusion, device position, and presence of device related thrombi were detected as well. The left superior pulmonary vein velocity was recorded at month 3 by TEE.

2.7. Statistical analysis

SPSS 17.0 software was used for the statistical analysis. Continuous data were expressed as the means ± standard deviations and categorical data as frequencies or percentages. Quantitative data were first analyzed to assess the normality of the distribution using Kolmogorov–Smirnov tests. Student's *t*-test was used to compare the differences in the LVEF, LA volume end-diastolic and left upper pulmonary vein velocity before LAA closure and follow-up. Student's t-test was also used to compare the differences among results obtained from 2D TEE, 3D TEE, cardiac CT, and fluoroscopy. The Peterson method was used to analyze the correlations among the 2D TEE, 3D TEE, and closure device size. The leakage detection efficiency postocclusion of 2D TEE and 3D TEE was compared by the Chi-square test. $P < 0.05$ was considered to be statistically significant.

3. Results

Among the 38 patients, 28 patients underwent LAA closure procedure and 10 patients were excluded due to significant decrease of LVEFs (LVEF < 40%, n = 3) and presence of at least 1 thrombi (0.5 cm to 3.0 cm) or spontaneous echo contrast (n = 7). The baseline demographic information of the patients was listed in Table 1.

The 3D full-volume datasets of the 28 patients were acquired in the 90° plane. The shape of the ostium and the number of lobes of LAA were clearly visualized, and the landing zone dimension and depth of LAA were obtained using 3D TEE as well. In this study, single-lobe LAAs were observed in 11 cases (39.29%), among which 4 showed depth smaller than the landing zone. The rest 17 (60.71%) were 8 bi-lobed and 9 multilobed LAA. The landing zone dimension of LAA was (20.86 ± 5.07) mm as revealed by 2D TEE, which showed statistical difference compared with the dimensions obtained from the 3D TEE (20.86 ± 5.07 mm vs 22.57 ± 5.71 mm, $P < 0.001$), CT (20.86 ± 5.07 mm vs 23.68 ± 5.61 mm, $P < 0.001$), and x-ray (20.86 ± 5.07 mm vs 22.45 ± 6.41 mm, $P = 0.004$), respectively. Meanwhile, statistical difference was noticed in the landing zone dimension of LAA as revealed by CT when comparing with those obtained from 3D TEE ($P = 0.022$) and x-ray ($P = 0.029$), respectively (Fig. 3). No statistical difference was noticed in the landing zone values of 3D TEE compared with that of x-ray ($P = 0.758$). The depth measured by 2D TEE was significantly smaller than 3D TEE (27.68 ± 4.51 mm vs 28.93 ± 4.52 mm, $P = 0.009$), CT (27.68 ± 4.51 mm vs 31.96 ± 4.34 mm, $P < 0.001$), and x-ray (27.68 ± 4.51 mm vs 29.14 ± 6.46, $P = 0.023$). Meanwhile, the depth measured by CT was larger than 3D TEE ($P < 0.001$) and x-ray ($P = 0.002$), respectively. No statistical difference was noticed in the depth measured by 3D TEE and x-ray ($P = 0.809$, Fig. 3).

The type of device was finally selected by the interventional cardiologists according to LAA anatomies and the measurements obtained using 3D TEE and x-ray angiography, as well as device

Table 1

Baseline clinical characters in 28 occlusion patients.

Variable	Values
Age, y	66.64 ± 8.52
Male/female	15/13
CHA2DS2-VASc score	3.86 ± 1.33
Age≥65 y, n, %	13 (46)
Age≥75 y, n, %	5 (18)
HF, NYHA, n, %	2 (7)
HTN, n, %	24 (86)
DM, n, %	4 (14)
Stroke/TIA, n, %	18 (64)
Coronary artery disease, n, %	5 (18)
LVEF, %	53.89 ± 6.06
Type of AF, n, %	
Persistent AF	22 (79)
Paroxysmal AF	6 (21)
Duration of the AF, n, %	
<1 y	5 (18)
1–3 y	8 (29)
>3 y	15 (53)
History of radiofrequency ablation, n, %	8 (28)
Warfarin, n, %	28 (100)
Indication, n, %	
Labile INR	8 (29)
Bleeding with OAC	4 (14)
Stroke with OAC	6 (21)
Patient preference	10 (36)

AF = atrial fibrillation, DM = diabetes mellitus, HF = heart failure, HTN = hypertension, INR = international normalized ratio, LAA = left atrial appendage, LVEF = left ventricular ejection fraction, NYHA = New York Heart Association, OAC = oral anticoagulation, TIA = transient ischemic attack.

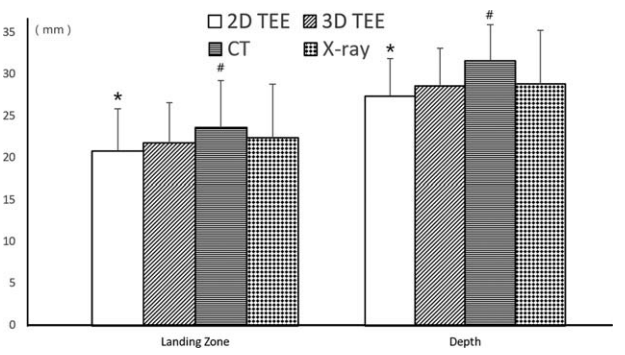

Figure 3. Measurement of the landing zone and the depth in 28 patients underwent LAA occlusion by 2D TEE, 3D TEE, cardiac CT, and x-ray. $^{*}P < 0.01$, compared with the 3D TEE, CT, and x-ray; $^{\#}P < 0.01$ compared with 2D TEE, 3D TEE, and x-ray. 2D TEE = two-dimensional transesophageal echocardiography, 3D TEE = real-time three-dimensional transesophageal echocardiography, CT = computed tomography, LAA = left atrial appendage.

designing characters. The Lefort was suggested to be more suitable for those single lobed LAAs with sufficient length to accommodate the device. The LAmbre was recommended for the patients with (i) multilobe LAA with a relatively high crest inside, (ii) 2 lobes of close sizes in a bi-lobe LAA, and (iii) LAA depth of less than the ostial dimension or less than 21 mm. Seven cases with single-lobe LAAs received occlusion using Lefort and 21 cases (including 4 single-lobe LAAs with shallow depth and 17

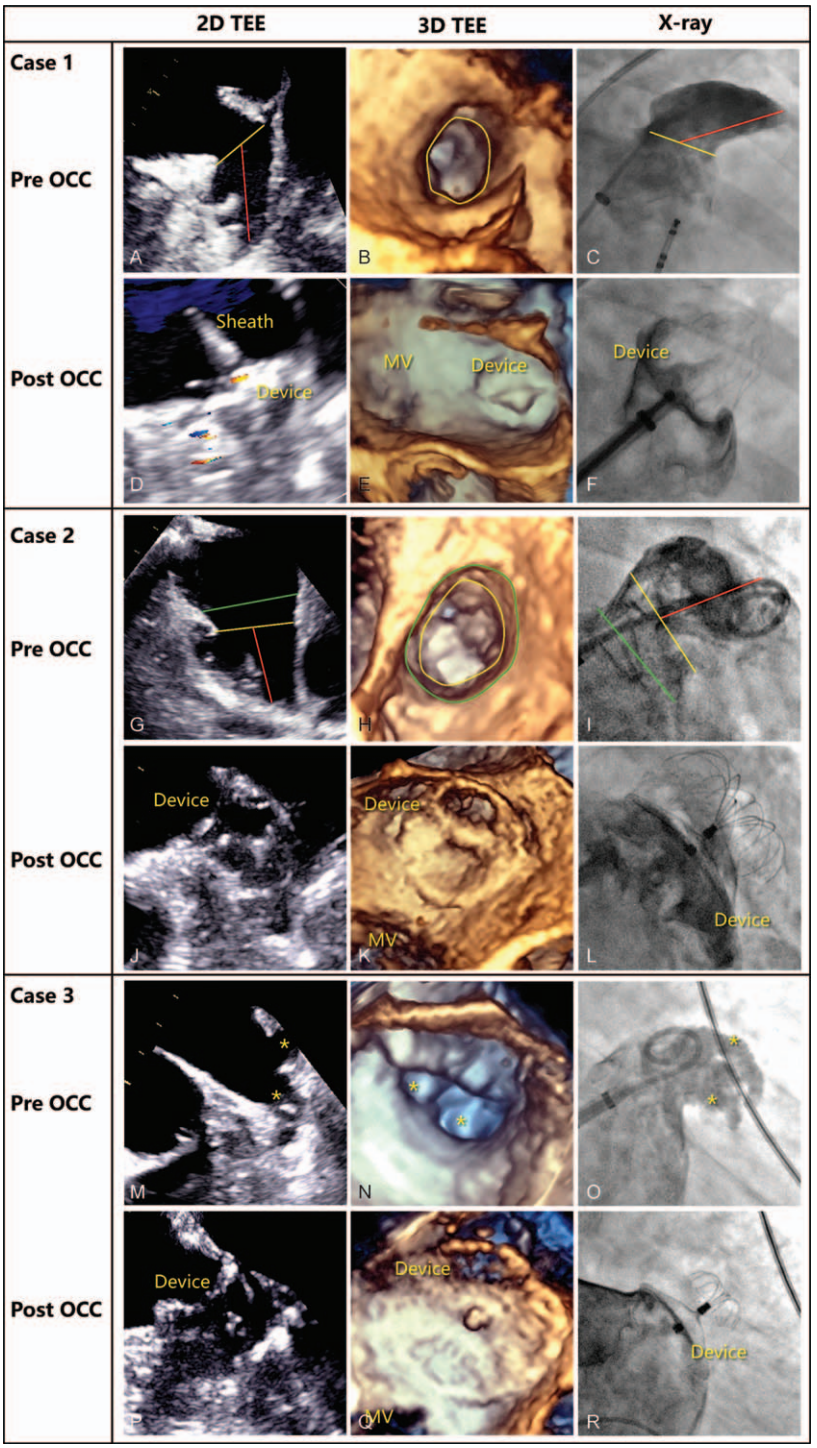

Figure 4. Strategies of closure for LAA with various morphologies. Case 1 was a patient with single-lobed LAA displayed by 2D TEE (A), 3D TEE (B), and x-ray (C), which showed a greater depth (red line) than ostium (line or circle in the yellow color) suitable for placement of Lefort device. The LAA was completely occluded with no significant leakage detected by 2D color flow imaging (D), 3D TEE (E), and x-ray (F). 3D TEE also indicated the anatomic relationship between the device and the mitral valve (E). Case 2 was also a single-lobed LAA with a limited depth comparing with the ostium. A regular LAmbre device was used for the closure. The landing zone (line or circle in the yellow color) and the ostium (line or circle in the green color) were measured prior to the procedure (G-I), and the closure was successful performed (J-L). Case 3 was a bi-lobulated (yellow star) LAA in 2D TEE (M), 3D TEE (N), and x-ray (O). The feature of this LAA was that there was a significant secondary lobe originating proximal to the main anchor lobe which was very challenging for occlusion. Then, a special LAmbre device was applied for occlusion. Both TEE and x-ray demonstrated full coverage of these two ostium of the LAA with no residual flow (P-R). 2D TEE = two-dimensional transesophageal echocardiography, 3D TEE = real-time three-dimensional transesophageal echocardiography, LAA = left atrial appendage, OCC = occlusion.

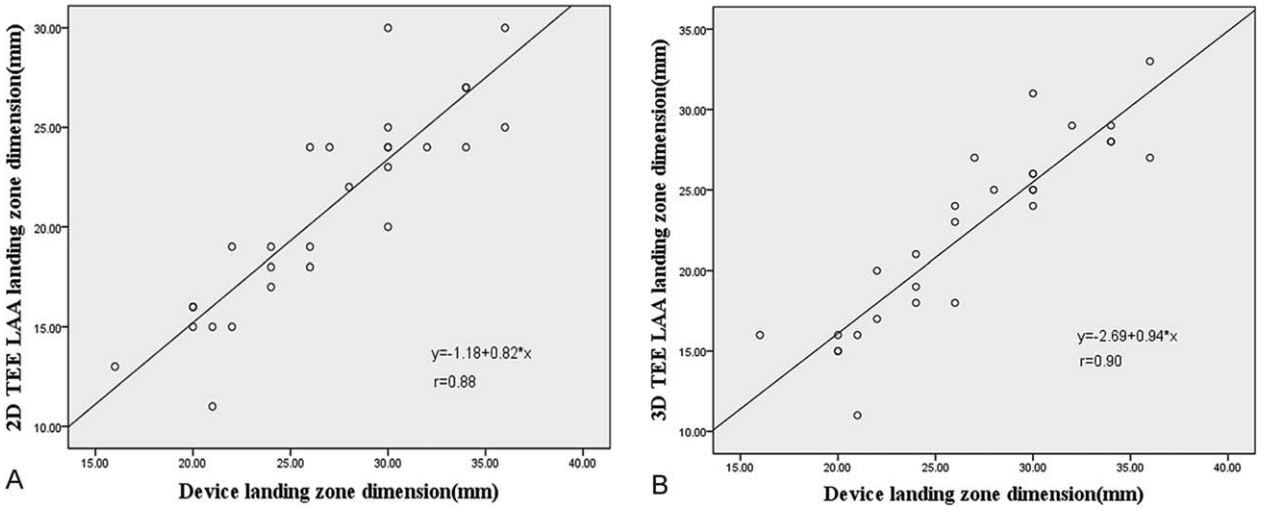

Figure 5. Correlation analysis between the device size and the dimension of LAA landing zone measured by 2D TEE ($r = 0.88$) and 3D TEE ($r = 0.90$) in 28 patients received LAA closure. 2D TEE = two-dimensional transesophageal echocardiography, 3D TEE = real-time three-dimensional transesophageal echocardiography, LAA = left atrial appendage.

non-single lobed LAAs) using LAmbre according to the LAA morphologies and the device selection standards above mentioned. Among the 21 patients underwent placement of LAmbre, 2 patients received closure using the special LAmbre device as 1 case was a close-sized bi-lobed LAA and the other one had a significant lobe originated near the landing zone of the main anchor lobe. The other 19 cases received closure using the standard device (Fig. 4).

The mean size of the closure device was (26.89 ± 5.47) mm. The landing zone determined using 2D TEE and 3D TEE were well correlated with the size of the closure device, particularly the 3D TEE (Fig. 5).

Upon a decision was made on the closure plan, the procedure was carried out under the guidance of 3D TEE and x-ray. Then, we compared the images of 2D TEE (Fig. 6A–E) and 3D TEE (Fig. 6F–J), regarding the interatrial septal puncture position, delivery of the sheath, pigtail catheter, released device, and peri-device leakage, respectively. Interatrial septum piercing was monitored using RT-3D TEE during the procedure. A tent-like sign was observed in the presence of piercing sheath enveloping the interatrial septum (Fig. 6F). One patient received interatrial septal puncture along the upper portion of septum, which resulted in the closure lasting for 75 minutes. The mean duration for the remaining patients was (49.66 ± 9.12) minutes.

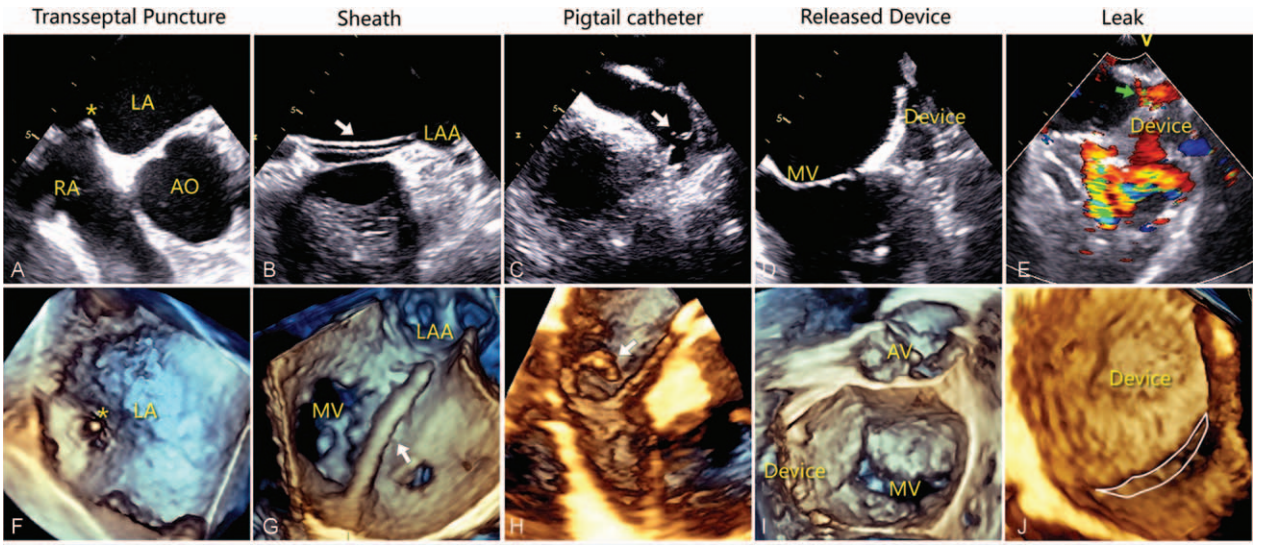

Figure 6. LAA closure procedures under the guidance of 2D TEE and RT 3D TEE. (A–E) The images of interatrial septal puncture position, sheath, pigtail catheter, release of device, and leak under the 2D TEE. (F–J) Image of interatrial septal puncture position, sheath, pigtail catheter, release of device, and leak under the 3D TEE. A "tent-like" sign could be seen when the puncture sheaths protruded the septum under the 3D TEE (F). The "en-face" view of the LAA ostium was displayed by RT 3D TEE (G), which identified the access of sheaths toward one of the ostium in a double-lobe LAA. 3D TEE is sensitive for the detection of the peri-device leakage which is featured by displaying the leakage area (J), while only a width of the shunt was observed for the per-device leakage in 2D TEE (E). 2D TEE = two-dimensional transesophageal echocardiography, 3D TEE = real-time three-dimensional transesophageal echocardiography, LAA = left atrial appendage.

Table 2

The TEE screening during LAA closure in 28 cases.

Variable	Values
Occlusion device used, n	1.11 ± 0.31
Occlusion success rate, %	28 (100)
LSPV peak systolic velocity, cm/s	60.79 ± 18.26
Complication, n, %	
Pericardial effusion/tamponade	0 (0)
Stroke related to operation	0 (0)
Device displacement/obstacle	0 (0)
Thrombi formed on device	0 (0)
2D-TEE	
Residual shunt around device ≤ 1 mm	1 (3.6%)
Residual shunt around device 2–3 mm	10 (35.7%)
3D-TEE	
Residual shunt around device ≤ 1 mm	3 (10.7%)
Residual shunt around device 2–3 mm	10 (35.7%)

2D TEE = two-dimensional transesophageal echocardiography, 3D TEE = real-time three-dimensional transesophageal echocardiography, LAA = left atrial appendage, LSPV = left superior pulmonary vein.

All the patients underwent the exchange of the piercing sheath within the left superior pulmonary vein and delivery of the pigtail catheter and the release of the closure device under the guidance of RT-3D TEE guidance (Fig. 6H). The average number of the closure device placement was 1.07, as smaller devices were used in 2 patients ultimately.

TEE images demonstrated closure was achieved in 17 patients with no leakage. However, in the resting 11 cases, 1 showed residual shunts (1 mm) and the other 10 showed residual shunts (2–3 mm) around the devices as visualized by 2D TEE. RT-3D TEE demonstrated the residual shunts were 1 mm in 3 cases and 2 to 3 mm in 10 cases, which showed no statistical significance compared with 2D TEE ($X^2 = 8.64$, $P = .11$). No clinically unacceptable residual shunts were observed (Fig. 6E and J). No patients showed evidence of pericardial effusion or tamponade. Meanwhile, no patients showed any other LAA closure-related complications (Table 2). Compared with the baseline level, no patients showed deterioration in the mitral regurgitation after LAA closure. Additionally, no obvious differences were noticed in the perfusion velocity of left superior pulmonary vein and LVEF after the procedure. Furthermore, RT-3D TEE could also display the movement of the mitral valve, the LAmbre sealing disk/Lefort umbrella, as well as the anatomic relationship between the 2 (Fig. 6I).

In the follow-up, no device displacement was noticed among the patients. Besides, no device related thrombi, pericardial effusion, and stroke were reported after LAA closure. The atrial puncture spot was recovered in all patients as revealed by the TEE. No statistical differences were noticed in the LVEF, left atrial volume, and the left superior pulmonary vein velocity before closure, as well as 1 month and 3 months post the procedure (Table 3). According to the RT-3D TEE performed 3 months after closure, all 3 residual shunts (1 mm) were vanished. Meanwhile, improvement or even elimination was noticed in 2 to 3 mm shunts in 6 patients based on the endothelialization time window (3 months) in Lefort and LAmbre.

4. Discussion

The major findings of this study were summarized as follows: (i) compared with conventional 2D TEE, RT-3D TEE was more accurate and intuitive in the pre-procedural planning and device sizing, sheathe and device operation during procedural and on-site occlusion evaluation. (ii) RT-3D TEE was a novel and valuable imaging modality in the percutaneous catheter-based LAA occlusion in AF patients, which could be recommended for routine clinical application.

The visualization of LAA via conventional thoracic echocardiography is still a challenge due to its anatomical position. TEE has been considered as the most commonly used imaging modality to evaluate the anatomical morphology and internal structure of the LAA, as well as identification of thrombi in it.[13] The morphology of the LAA varied among individuals. Bi-lobed or multi-lobed LAA were noticed in about 50% of the autopsy study,[14] and the lobes were not localized on the same plane. Conventional 2D TEE is not adequate to display the morphology of LAA through multiple views as it can only display the LAA section by section due to technical limitations. Therefore, it is difficult to precisely determine the number of lobes and the maximal dimension of LAA ostium, which hampers the planning and accomplishing of a closure procedure in patients with a multi-lobed LAA. Unlike the conventional 2D TEE, the 3D TEE is convenient to obtain the full volume data and the presence of lobe in the LAA.[15] Our study indicated RT-3D TEE was effective for the LAA closure in clinical practice, which was mainly featured by accurate determination of the morphology and number of LAA orifice, the position of massive trabecular muscles in the cavity of atrial appendage, as well as the landing zone of the LAA. Compared with the 2D TEE, RT-3D TEE brings about more information about the anatomical structure of the LAA, which is helpful for the selection of closure device. Meanwhile, the En-face view of the closure device after placement could be provided by RT-3D TEE, together with the position of the device in the heart chamber and the location between the adjacent structures. All these contribute to the evaluation of closure in an accurate manner.

Selection of occlusion device is crucial for the safety and efficiency of the closure procedure. As the LAA anatomy varies considerably among individuals, it is reasonable to conclude that selection of appropriate device fitting the LAA morphology is the priority for the procedure. In this study, 2 closure devices including LAmbre and the Lefort were used. The Lefort, designed as umbrella-like profile accomplishing occlusion by plug-in and expanding, is most appropriated for the management of single lobe LAAs with greater depth than orifice size. It is a challenge for

Table 3

Follow-up echo at 1 month, 3 month postclosure ($\bar{x} \pm s$).

Time	N	LVEF (%)	LSPV V_{max} (cm/s)	LA volume end-diastolic (mL)
Pre	28	53.89 ± 6.06	58.25 ± 14.83	75.68 ± 19.74
1 month post	28	54.07 ± 5.58	–	78.93 ± 17.38
3 month post	28	54.50 ± 5.35	61.75 ± 13.17	78.29 ± 17.69

LA = left atrium, LSPV = left superior pulmonary vein, LVEF = left ventricular ejection fraction.

Lefort in the LAAs with large orifices, shallow depth, and non-single lobed LAAs especially multi-lobed LAAs. LAmbre with a landing umbrella and a seal disk could selectively occlude a main lobe of the LAA and cover the rest smaller lobes by the seal disk in nonsingle lobe patients. The device is appropriate for the management of bi-lobed or multiple-lobed LAA. Compared with the Lefort closure device, the LAmbre device is less demanding on the depth of LAA. The device could be placed in the presence of a height of >1 cm between top of trabecula to the internal orifice. Based on our practical experiences, the selection indication of these 2 devices was further supported. In this study, among the 11 patients with single lobed LAA, 4 received the LAmbre device rather than Lefort due to larger orifice width than the depth. The LAmbre device is more effective for the closure of bi-lobed LAA, multilobed LAA, as well as LAA depth less than orifice dimension. Moreover, the special LAmbre device could be applied as a solution for some challenge structured LAAs such as a LAA with 2 large lobes of a similar size separated by pectinate muscles.

The accurate evaluation of the size of the landing zone is crucial for the selection of LAA closure device. Device instability and peri-device leakage may occur in cases of using a smaller sized device. On the other hand, a larger device might bring the risks of LAA perforation and cardiac tamponade during and post the procedure. According to the Watchman LAA occlusion protocol, the maximal dimension of LAA orifice was measured in the 0°, 45°, 90°, and 135° planes by 2D TEE.[16,17] However, it may be difficult to obtain the accurate ostial dimension of the LAA using 2D TEE as the 2D TEE was not parallel to the ostial plane in most cases.[18] The 3D TEE Flexi Slice calculation mode, similar with CT multiplanar reconstruction, can display cross-sectional images of the LAA orifice from any orientation or angle, as opposed to 1 section image via 2D TEE. Such technique could effectively eliminate the measurement error and provide strong evidence supporting the selection of a particular device. In line with the previous studies,[13,15] our results showed the association of the dimension of landing zone and the closure device type revealed by RT-3D TEE was much higher than that of 2D TEE. Meanwhile, using the 3D Flexi Slice mode, selection of closure device was achieved as the anatomical structures of LAA could be visualized at any angle in the 3D image plane, including LAA ostial pattern, lobes, and internal anatomy such as the tuberculations within each lobe.

Cardiac tamponade and pericardial effusion may occur after closure, which are often attributed to improper usage of wire or sheath, as well as repeated device adjustments, improper device placement in the LAA, and inappropriate atrial septal puncture.[19] As is known to all, atrial septal puncture, the first step in the occlusion, is important for the subsequent procedures. The puncture point must be located along the inferior posterior interatrial septum to ensure that the sheath and the device could reach the LAA through this opening and maintain an appropriate orientation with respect to the long axis of LAA. Coaxiality is crucial for the appropriate closure angle and orientation. Also, it contributes to the occlusion of the LAA without significant residual shunting.[20,21] As previously described, RT-3D TEE offered a full view of the interatrial septum, which allowed for the cardiologists to visualize the optimal puncture site.[22] In this study, improper puncture was noticed in only 1 case, which occurred in the upper portion of the atrial septum resulting in poor coaxiality and the deformation of the device following its first release, as well as residual leakage. On this basis, repeated operation and the prolongation of the procedure were required.

In terms of evaluation of on-site occlusion effects, RT-3D TEE can clearly depict the morphology of the LAA ostium following the release of the device, as well as the relationship between the device and the mitral valve. The space between the device and LAA ostium should be the anatomic basis of residual shunt which is the key aspect of the closure evaluation. Our results showed that residual shunt of less than 1 mm was identified in 3 cases by 3D TEE, whereas only 1 case by the 2D TEE, despite no statistical difference was noticed as the sample size was small in this study. 3D TEE was effective to directly visualize the range of the residual leak compared to conventional 2D TEE. To be exact, 2D TEE can only demonstrate the leakage between the LAA wall and the device in various view, whereas RT-3D TEE can display the entire leakage around the device in 1 view. Besides, RT-3D TEE can also display the dynamic movement of mitral valve and the device during the cardiac cycle.

Indeed, there are limitations in this study. The RT-3D TEE technique is superior to the 2D TEE for the imaging of the LAA, catheter, sheathe, and the device. However, the imaging of color flow leakage by RT-3D TEE is poor than 2D TEE due to limited temporal resolution. In addition, 3D TEE involves a very skillful operation to ensure fast reconstruction of high quality image; otherwise, it would be time-consuming and may slow down the whole procedures.

5. Conclusion

Both 2D TEE and 3D TEE are valuable imaging modality for LAA closure during the peri- procedure stage. Compared with conventional 2D TEE, RT-3D TEE allows for a better intuitional and stereoscopic visualization of the LAA and catheter, which facilitates the preoperative screening and intraoperative monitoring of device delivery.

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