



Catheter-based left atrial appendage occlusion procedure: role of echocardiography

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Atrial fibrillation is a common, clinically significant arrhythmic disorder that results in increased risk of morbidity and mortality in affected patients. Atrial fibrillation is more prevalent among men compared with women and the risk for developing atrial fibrillation increases with advancing age. Ischaemic stroke is the most common clinical manifestation of embolic events from atrial fibrillation. While anticoagulation treatment is the preferred treatment, unfortunately, many patients have contraindications for anticoagulation treatment making this option unavailable to them. Previous data have shown that most thrombi that form in association with non-valvular atrial fibrillation occur in the left atrial appendage (LAA). It has been suggested that isolating the LAA from the body of the left atrium might reduce the risk of embolic events and that LAA obliteration may be a treatment option for patients with atrial fibrillation who are not candidates for anticoagulation treatment. Several procedures have been developed for isolation of the LAA, including surgical procedures as well as catheter-based ones. In this paper, we will review the currently available techniques, emphasizing the catheter-based ones. We will examine the increasing role of real-time three-dimensional transoesophageal echocardiography for appropriate screening and patient selection for these procedures, intra-procedural guidance, and follow-up care.

Keywords

Three-dimensional echocardiography • Left atrial appendage • Appendage occlusion

Introduction

Atrial fibrillation is a common, clinically significant disorder that results in increased risk of morbidity and mortality in affected patients.¹ Atrial fibrillation is more prevalent among men compared with women and the risk for developing atrial fibrillation increases with advancing age. Systemic embolization can occur at any point during the course of atrial fibrillation. Ischaemic stroke is the most common clinical manifestation of embolic events from atrial fibrillation. Chronic antithrombotic therapy for the prevention of embolic events has become the mainstay of the treatment of atrial fibrillation, regardless of the approach chosen for the treatment of the arrhythmia ('rhythm control' vs. 'rate control'). While anticoagulation treatment is the preferred treatment, there are still concerns regarding this treatment: even with optimal management and achievement of international normalized ratio (INR) goals, the stroke risk is not completely eliminated, strict monitoring and dose adjustments are required to assure INR in the

target range, and many patients have contraindications for anticoagulation treatment making this option unavailable to them.

Previous data have shown that most thrombi that form in association with non-valvular atrial fibrillation occur in the left atrial appendage (LAA). It has been suggested that isolating the LAA from the body of the left atrium might reduce the risk of embolic events and that LAA obliteration may be a treatment option for patients with atrial fibrillation who are not candidates for anticoagulation treatment.^{2–4}

Left atrial appendage obliteration procedures

Surgical procedures

- (i) Intra-atrial procedures—LAA ligation by intra-atrial running suture or stapling of the LAA opening.

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- (ii) Extra-atrial approach with clamping and ligating of the base of the LAA and excision of the LAA.

Several studies examined the safety and efficacy of surgical exclusion of the LAA during bypass surgery, MAZE procedures, and mitral valve surgeries. Some studies were able to demonstrate a benefit from routine obliteration of the LAA;² however, others were unable to show a benefit and even demonstrated an increased stroke risk following the procedure.^{5–8} It is worth noting that successful isolation of the LAA was not achieved in all patients; in fact, in most of the studies, incomplete obliteration was found in more than 30% of study subjects. Incomplete LAA obliteration can result in increased embolic event risk since it creates a chamber with significant blood stagnation which is still in direct communication with the main left atrium.

Catheter-based procedures

Two devices have been introduced into use for percutaneous LAA obliteration; the PLAATO system (Appriva Medical; Figure 1A) and the WATCHMAN device (Atritech, Inc., Minneapolis, MN, USA; Figure 1B). Preliminary results documented the feasibility and short-term success rate of LAA occlusion by percutaneous device implantations.^{9–13}

Percutaneous LAA occlusion has demonstrated that complications associated are typically clustered in the early periprocedural period. As seen with other interventional procedures, complications significantly decrease in frequency with operator experience. While there has been a higher overall complication rate associated with LAA closure than warfarin treatment, the functional impact of these events favours LAA closure. Thus current data appear to favour the safety profile of the left atrial closure with device implantation.¹⁴

Echocardiographic assessment of the left atrial appendage

Percutaneous LAA obliteration procedures rely heavily on transoesophageal echocardiography (TEE) for anatomical screening, device implantation guidance, and follow-up surveillance. Over the course of the past few years, real-time three-dimensional (RT3D) TEE has become available and has been utilized to guide these procedures, in addition to multiplane two-dimensional (2D) TEE. Previous data have shown the feasibility and accuracy of RT3D TEE in imaging the LAA^{15,16} and guidance of catheter-based intracardiac procedures.¹⁷ The technique, possible advantages, and added benefit of RT3D imaging for the screening, guidance, and follow-up of LAA occlusion procedures are discussed in the following paragraphs.

Background

Over the past several years, improvements in transducer technologies have allowed for the development of a miniaturized full matrix array transducer that can be coupled with a transoesophageal probe. This allows for the acquisition of high-quality RT3D images due to closer proximity to the heart (avoidance of bone and air attenuation) and the use of higher ultrasound frequencies.

There are three types of data acquisition modes available using the new transducer:

- (i) Three-dimensional zoom mode—in this mode, a truncated pyramidal data set is generated. The size of this data set is manually adjusted to incorporate the region of interest. The image is then presented in real-time and can be rotated in all three axes to present the structure examined from different perspective (without any further manipulation of the probe).
- (ii) Narrow-angle mode—in this mode, a thicker 'slice' of the heart is generated and presented in real time. The image can be then rotated in all axes.

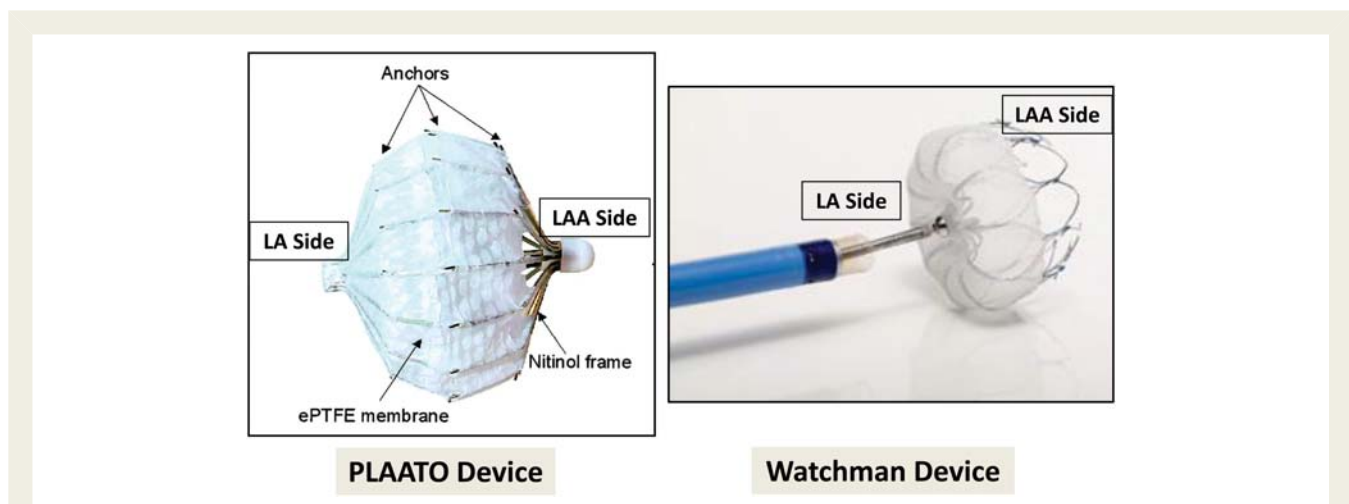


Figure 1 Percutaneous left atrial appendage closure devices. The PLAATO device and the Watchman device are shown. The PLAATO device is a self-expanding nitinol frame, covered by an occlusive polytetrafluoroethylene membrane. The Watchman device is a filter device, similarly made of a self-expanding nitinol frame covered by a permeable polyester fabric membrane (LA, Left Atrium; LAA, left atrial Appendage).

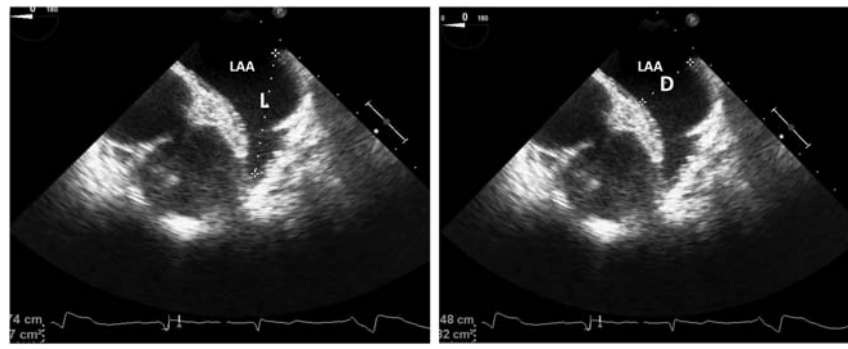


Figure 2 Pre-procedure measurements. A biplane, two-dimensional view of the left atrial appendage is seen. Measurements are performed at every view; the left atrial appendage opening diameter (D) and the left atrial appendage length (L). These are performed to verify suitable appendage dimensions for device implantation (LAA, left atrial appendage).

- (iii) Wide-angle full-volume mode—in this mode, a large, pyramidal data set is acquired over 4–7 cardiac cycles (EKG gating required). This allows for larger volumes of cardiac structures to be displayed. The image can then be further processed with cropping along any plane and rotating in all three axes. In this mode, 3D colour Doppler imaging is also possible.

These different imaging modalities allow accurate and detailed anatomic evaluation of intracardiac structures, as well as intracardiac catheters and devices.

Left atrial appendage occlusion procedure

Before performing an LAA occlusion procedure, a screening TEE is done to assess anatomical suitability for the procedure, as well as rule out any possible contraindications (i.e. presence of an LAA clot). Most importantly, the LAA is measured both for the size of its orifice and for its length to assure that dimensions are within the available device range (Figure 2).

The occlusion procedure is performed in the interventional laboratory, often with the patient under general anaesthesia. TEE guidance, as well as intermittent fluoroscopic guidance, is utilized throughout the procedure.

Access to the left atrium is achieved via central venous access (through the femoral vein) and a transseptal puncture. A guiding catheter is then passed through the transseptal puncture and a pigtail catheter is advanced towards the LAA. The use of a pigtail catheter for this purpose is preferred in order to minimize the possible risk of perforation of the LAA. An angiogram of the LAA is then performed with contrast injection (Figure 3). The pigtail catheter is replaced with the delivery system carrying the closure device. The device is advanced towards the LAA opening and proper positioning is verified by echocardiography. Once the location is verified, the device is expanded to occlude the LAA orifice (Figure 4A). Colour Doppler is used to assess for any flow around the device (Figure 4B). If no flow is detected and the LAA appears completely isolated from the main left atrium, the

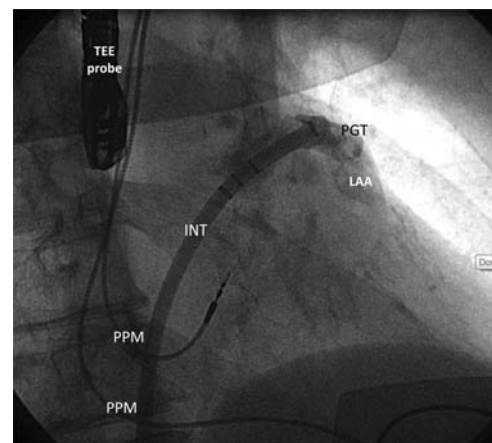


Figure 3 Left atrial appendage angiogram. A fluoroscopic view of the left atrial appendage is seen. There is an introducer (INT) and a pigtail catheter (PGT) in the left atrium. The tip of the pigtail catheter is in the opening of the left atrial appendage and a contrast injection is performed, delineating the appendage anatomy (LAA, left atrial appendage; PPM, permanent pacemaker wires).

device is deployed and the catheters removed (Figure 5). If, however, the position is suboptimal, the device can be repositioned until satisfactory occlusion of the LAA is achieved. Once the device is deployed, repeat assessment of the device position, as well as colour Doppler interrogation, is performed to verify the complete occlusion of the LAA and lack of residual communication around the device.

TEE follow-up is performed at standard intervals post device implantation. These TEE studies are performed to assess for the presence of any LAA or left atrial clot, assessment and confirmation of the device position, presence or absence of any residual LAA flow around the device, and presence or absence of any residual inter-atrial shunt.

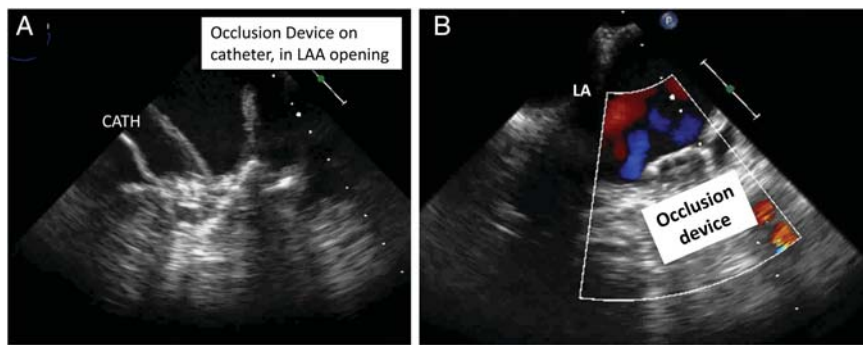


Figure 4 Device in place. (A) An occlusion device (Watchman) positioned in the left atrial appendage opening, as seen on two-dimensional imaging. The device has not been deployed yet; it is still attached to the delivery catheter (CATH). (B) Colour Doppler evaluation of the closure success is performed. Note that there is no colour Doppler evidence for any flow around the device (LAA, left atrial appendage).

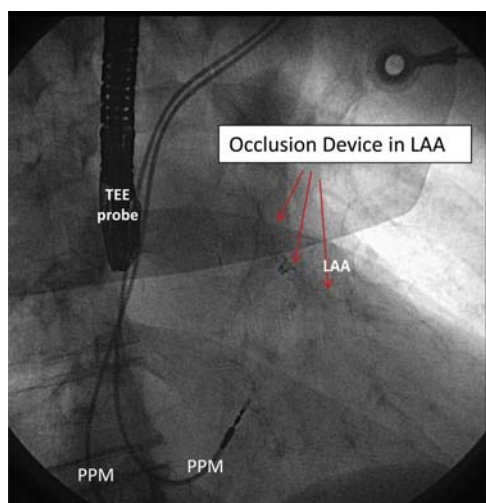


Figure 5 Fluoroscopy of the occlusion device. Fluoroscopic evaluation of the device (Watchman) position (LAA, left atrial appendage; PPM, permanent pacemaker wires).

Introduction of real-time three-dimensional transoesophageal imaging

Over the course of the last 3–4 years, RT3D imaging has been implemented in addition to routine multiplane 2D imaging for percutaneous left atrial occlusion procedures (for screening, procedure guidance, and follow-up). Our laboratories have been participating in the PROTECT-AF and Continued Access PROTECT-AF trials and since 2006, and RT3D TEE imaging has been added to our imaging protocol for these patients since 2008. In our experience, RT3D imaging was helpful for:

- (i) accuracy in assessing LAA anatomy;
- (ii) visualization of the various stages of the occlusion procedure including the transseptal puncture and all catheter manipulations in the heart;

- (iii) device positioning and achievement of proper LAA exclusion;
- (iv) assessing for the presence of residual communication between the LAA and the main left atrium;
- (v) evaluation during follow-up studies for proper obliteration of the LAA as well as for the possible presence of procedure complications.

Assessing left atrial appendage anatomy

The procedure protocol requires measuring the LAA orifice in multiple imaging planes. The measured diameters on the various planes can vary significantly (in our experience—up to 12 mm difference between the diameters obtained at 0° and 135°). The RT3D zoom mode allows *en face* visualization of the LAA opening (Figure 6). This can be done in real-time, allowing for qualitative assessment of the anatomy. By post-processing, the LAA opening area can be directly measured, without a need for any geometrical assumptions. This can be done using full-volume or 3D zoom images obtained by any imaging angle. Once loaded on the post-processing software, the imaging planes can be aligned such that the LAA opening is viewed directly from above. The opening can then be traced directly to obtain a measurement of its area. By advancing the cropping plane into the appendage, the measurement can be repeated at any desired depth within the LAA. Using these techniques confirms that the LAA opening may have an irregular or elliptical shape and allows easy appreciation of the anatomy and suitability for device implantation, both by the echocardiographer and the interventionalist. Unsuitable LAA anatomy can result in exclusion from the procedure, and occasionally, this can only be appreciated using RT3D imaging with *en face* visualization of the LAA opening. We had one case where the screening TEE was done utilizing 2D imaging only. The LAA mouth was measured in several planes. The largest diameter obtained was assumed to be sufficient for implantation of the smallest device. However, during the procedure, while utilizing RT3D imaging, it was seen that the LAA had an oval-shaped opening, and the diameter that was measured on the 2D TEE was the major axis of the ellipse, and the minor axis was significantly smaller such that even the smallest device could not fit. In

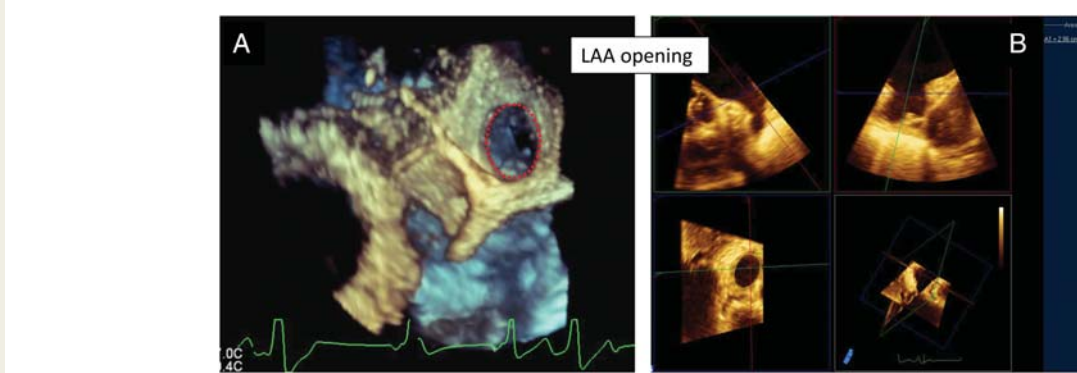


Figure 6 Real-time three-dimensional imaging of the left atrial appendage. (A) Left atrial appendage as seen using the three-dimensional zoom mode in an *en face* view from the main left atrial perspective. The shape of the opening can be clearly delineated (in this case, oval shape). (B) Post-processing of a full-volume image of the left atrial appendage. Accurate positioning the cropping planes can be achieved such that a clear visualization of the left atrial appendage opening can be obtained, traced, and accurately measured for area and perimeter (LAA, left atrial appendage).

this case, an attempt was made to implant a device, but as predicted from the 3D imaging, it could not be placed in the LAA. In the second case, the screening TEE was done utilizing RT3D imaging which showed that the LAA had unfavourable anatomy for implant (too small opening as well as too short), so the patient was excluded from the trial.

The LAA can occasionally be septated and divided into several lobes. The separating septa may be seen only from certain angles on the 2D imaging, and the anatomy needs to be ‘mentally reconstructed’. It is important to understand precisely at what depth, these septa transverse the appendage, as well as whether they cause narrowing of the orifice of the LAA in order to verify anatomical suitability for the procedure and optimize device sizing. Anatomic definition can be obtained with contrast angiography (a 2D imaging modality) as well as RT3D imaging. The 3D zoom mode, as well as the full-volume acquisition with post-processing, allows for the visualization of the entire LAA, including the lobulated area, thus minimizing the need for contrast injections.

Procedure guidance—visualization of intracardiac catheters and devices

At all stages of the procedure, full visualization of the intracardiac catheters and devices is extremely important in order to avoid complications. Two-dimensional imaging is a tomographic technique, allowing for the visualization of only a ‘slice’ of the heart at any given time. Often, catheters can be seen on the 2D images; however, it is hard to be certain about the location of the tips of the catheters as they may be out of the imaging plane. RT3D imaging (both the live modes and the full-volume modes) allows imaging of the entire intracardiac portion of all catheters, thus increasing the confidence of catheter manipulations by the interventionalist. Although an LAA angiogram is generally performed prior to introducing the device into the left atrium, advancement of the device towards the appendage is done under continuous visualization by TEE (Figure 7). Using RT3D imaging allows clear delineation of the device tip as it is advanced

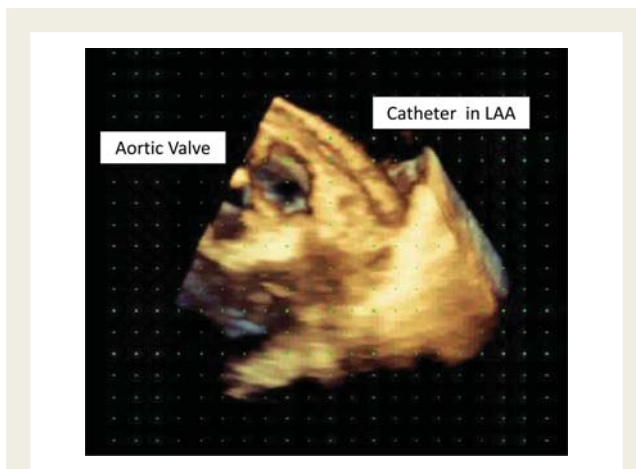


Figure 7 Intracardiac catheter. Guiding catheter in the left atrial appendage. The aortic valve is clearly seen and the full path of the catheter can be ascertained (LAA, left atrial appendage).

through the guide wire, avoiding nearing structures like the left upper pulmonary vein or the left atrial free wall.

Device positioning and achievement of proper left atrial appendage exclusion

Once the device is positioned in the LAA, its position is assessed prior to final deployment. The RT3D zoom mode with *en face* visualization of the device allows assessing the anatomical fit of the device (Figure 8A). If the placement appears suboptimal, the device can be adjusted and re-positioned until satisfactory result has been achieved (Figure 8B). Using both the 3D zoom mode and simultaneous biplane 2D imaging allows quick assessment of the device position without the need to manually change the imaging angle from 0° to 135° repeatedly.

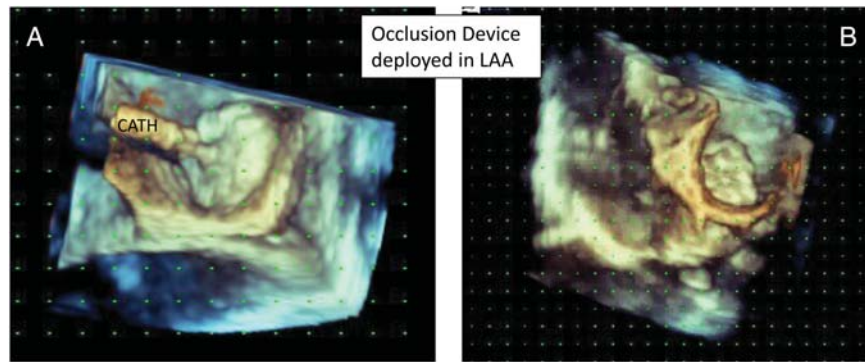


Figure 8 Final result. (A) Real-time three-dimensional view of the deployed occlusion device, still attached to the delivery catheter; *en face* view of the device, as seen from the main left atrium. This allows for anatomic assessment of the adequacy of the closure before final detachment of the device. (B) Occlusion device deployed and detached from the delivery catheter as seen *en face* from the left atrial perspective.

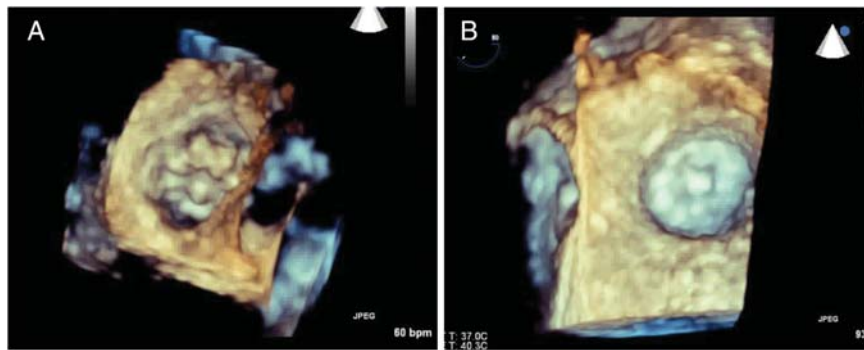


Figure 9 Follow-up assessment of device positioning. (A) Occlusion device in left atrial appendage as seen *en face* utilizing the three-dimensional zoom mode. The device chosen was apparently too small, resulting in displacement and suboptimal positioning with residual communication between the left atrial appendage and the main left atrium. (B) *En face* view of a properly sized and positioned closure device. The complete occlusion of the left atrial appendage can be easily delineated on this image and was confirmed by colour Doppler imaging as well.

Presence of residual communication between the left atrial appendage and the main left atrium

Once the position of the device appears anatomically satisfactory, colour Doppler 2D imaging is used to assess whether any residual communication exists between the LAA and the main left atrium. With current techniques, colour Doppler is only available with the full-volume acquisition mode. While this allows for assessing for residual shunting, since it occasionally requires some post-processing, this stage is more easily performed utilizing the 2D imaging mode.

Follow-up studies and complications

At the end of the procedure, echocardiography is used to assess for the presence of any possible immediate complications. These may include pericardial effusion and tamponade and device dislodgement and embolization. Following the procedure, TEE is performed at standard intervals to assess the long-term results, as well as any new complications. Once again, device positioning is

easily appreciated using the 3D zoom mode with *en face* visualization of the LAA opening (Figure 9). Colour Doppler is utilized for assessing residual communication between the LAA and the main left atrium. Both 2D and 3D imaging are used to evaluate for the presence of any intra-cardiac clots (both in the obliterated LAA and outside the LAA; Figure 10).

Limitations of real-time three-dimensional imaging

While the detailed anatomic evaluations, as well as the volumetric assessment of cardiac chambers, are clearly superior to 2D imaging, there remain still a few limitations to the technique.

The temporal resolution on the RT3D images is reduced when compared with 2D imaging. This makes the image appear to move less 'smoothly' than what we have become accustomed to on 2D imaging. This is mainly a concern when imaging highly mobile

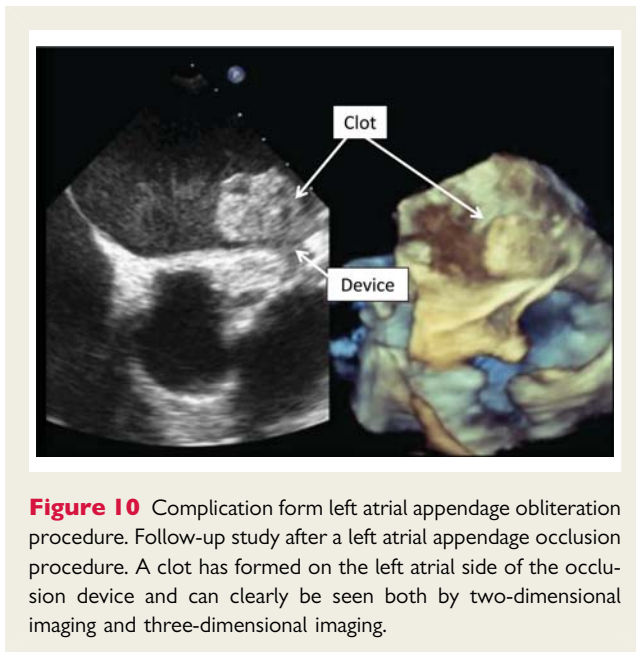


Figure 10 Complication from left atrial appendage obliteration procedure. Follow-up study after a left atrial appendage occlusion procedure. A clot has formed on the left atrial side of the occlusion device and can clearly be seen both by two-dimensional imaging and three-dimensional imaging.

structures like vegetations, but less troubling when imaging structures that move with the heartbeat.

Specific training in RT3D image acquisition, imaging protocols, standardization of views, and interpretation are clearly required; however, currently, there are still no formal professional guidelines for these training requirements. It is hoped that as the technique becomes wider spread and requested by echocardiographers, as well as interventionalists, professional associations like the American Society of Echocardiography will create a task force to generate appropriate training guidelines.

Summary

Catheter-based LAA occlusion procedures are becoming a possible alternative for the treatment of patients with atrial fibrillation and contraindications to oral anticoagulation therapy. These procedures are done utilizing TEE surveillance and guidance. The currently available RT3D imaging is a powerful additional tool that may help in improving the safety profile of the procedure. It allows accurate assessment of LAA anatomy, suitability for device implantation, continuous visualization of all intracardiac devices and catheters during the procedure, and clear delineation of device positioning in the LAA. In our experience, RT3D imaging is a useful adjunct in all catheter-based LAA occlusion procedures.

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