The role of echocardiography in percutaneous left atrial appendage occlusion

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Percutaneous device closure of the left atrial appendage (LAA) has been introduced in the last decade as a minimally invasive alternative treatment to long-term anticoagulation to reduce the risk of thrombo-embolism in patients with atrial fibrillation. Echocardiography is an essential tool at all stages of the procedure. Pre-procedural echocardiography is used to screen suitable candidates and to define LAA morphology and dimension; peri-procedural transoesophageal or intracardiac echocardiography has a major role in guiding, delivery, and deployment of the device, for screening of procedural complications and for assessing procedural success; and post-procedural echocardiography is important in the surveillance and monitoring of long-term outcome. This article aims to outline the role of echocardiography at each stage of LAA occlusion.

Keywords Echocardiography • Atrial fibrillation • Left atrial appendage occlusion

Introduction

Atrial fibrillation (AF) is responsible for more than 15% of all strokes.1 Anticoagulation with warfarin is effective at reducing the risk of thrombo-embolic events in AF2 but necessitates regular blood monitoring, can be disrupted due to frequent interactions with concomitant medications such as antibiotic therapy, and is associated with increased bleeding risk, which is estimated at 1–2% per year for major haemorrhagic complications.3 Consequently, despite demonstrable benefit, alternatives to warfarin therapy have long been sought in patients with AF.4

The vast majority (86–91%) of left atrial (LA) emboli originate in the LA appendage (LAA),5,6 a tubular structure measuring 2–4 cm in length and attached to the LA. In the presence of AF, the LA stretches and dilates, promoting stagnation of blood flow and thrombus formation in the LAA. An emerging option for patients with AF who cannot safely receive anticoagulation has been to obliterate the LAA to remove a potential nidus for thrombus formation. Direct surgical amputation has been performed routinely to minimize the risk of future thrombo-embolism, most commonly as an adjunct to mitral valve (MV) surgery often in rheumatic heart disease. Several methods have also been developed to achieve this by percutaneous or transpericardial approaches, the primary aim being to exclude blood flow into and out of the LAA. Percutaneous LAA occlusion has the advantage of being a minimally invasive treatment for patients in whom long-term anticoagulation treatment is deemed unsuitable, and may be equivalent to treatment with warfarin in those individuals considered at moderate-to-high risk of thrombo-embolism.7

Percutaneous left atrial appendage occlusion devices

There are currently two commercially available devices designed for LAA occlusion: the WATCHMAN LAA closure device (Boston Scientific Natick, MA, USA, previously Atritech, Inc., North Plymouth, MN, USA) and the Amplatzer cardiac plug or ACP (St Jude Medical Inc., MN, USA, previously AGA Medical Corp., Plymouth, MN, USA). The Percutaneous Left Atrial Appendage Transcatheter Occlusion (PLAATO) device (ev3 Inc., Plymouth, MN, USA) was the first device to be introduced in 2002 with feasibility studies showing a low risk of complications associated with implantation and a reduction in the predicted risk of stroke at 5 years.7 The PLAATO device has been removed from the market for commercial reasons, although all three have European CE marking approval, whereas none have received approval from the US Food and Drug Administration.

The PLAATO implant consists of a spherical nitinol self-expanding metal cage with multiple struts that support an occlusive membrane of expanded polytetrafluoroethylene (an echo-reflective material due to microscopic trapped air), which
The WATCHMAN System comprises a self-expanding nitinol frame structure with fixation barbs covered with permeable polyester fabric that allows blood to flow into or out of the LAA but excludes passage of thrombi (Figure 1B). The shape is semi-spherical on the LA side and tapered towards the appendage side. Device diameters range from the smallest at 21 mm, increasing by 3 mm to a maximum of 33 mm. A size is chosen such that the device diameter larger than the LAA ostium is chosen to ensure sufficient occlusion of the LAA and promotes healing (Figure 1A). Devices of different sizes were available, measuring from 15 to 32 mm in diameter. The device selected was usually 20–40% larger than the orifice of the LAA. If the result of device implantation was suboptimal, the device could be collapsed back into the delivery sheath and replaced with another size.

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Access in both systems is obtained via a transseptal sheath in the femoral vein through which the delivery catheter is deployed. A transseptal puncture is performed and the implant is introduced into the LA. The delivery sheath allows injection of contrast in the LAA and proximal to the device to facilitate accurate placement and angiographic assessment of leakage, and also allow repositioning and adjustments to be made before final deployment. LAA anatomy tends to be highly variable, often with multiple lobes and therefore no single device is likely to be suitable for all patients.

**Pre-procedural echocardiographic assessment**

Multiplanar transoesophageal echocardiographic (TOE) assessment is currently the main modality used to screen suitable candidates for device closure of the LAA. The LAA cannot be fully examined by transthoracic echocardiography (TTE). The main echocardiographic exclusion criterion is the presence of thrombus in the LAA, although the presence of spontaneous echo contrast (SEC) and significant valve disease should be noted. Once thrombus has been excluded, TOE is used to assess LAA morphology, ostial dimension, and maximum length of the dominant lobe to provide a series of baseline measurements for procedural planning. Baseline LA dimensions in the anteroposterior and craniocaudal planes (0° and 120°, respectively) are noted and an assessment of the ostial dimensions of the LAA is performed to provisionally determine the size of the device required. Ostial dimensions are usually made from four mid-oesophageal views on two-dimensional (2D) TOE: (i) 0–20° in the four-chamber view, modified by slight flexion or withdrawal to open the LAA (Figure 2A); (ii) 45–60° at the level of the aortic valve (Figure 2B); (iii) 90° in the apical two-chamber view (Figure 2C); and (iv) 120–135° in the long-axis view, turned anti-clockwise, often useful to open subsidiary lobes within the LAA (Figure 2D). Typically, a device with a diameter larger than the LAA ostium is chosen to ensure sufficient anchoring for stable positioning. Additional measures are made in pre-assessment for ACP positioning ~10 mm into the LAA to size for the position of the anchoring lobe (Figure 2B). The maximum length of the dominant lobe of the LAA is then recorded.
Device sizing is crucial to ensure device stability, optimum sealing of the LAA ostium, and minimize the risk of leakage, which could provide a new source of future thrombo-embolism. Finally, assessment of LA inflow and outflow will provide a baseline assessment of LA function, pulmonary venous anatomy and flow, and transmural flow, all of which can be theoretically altered following device deployment. The diameter of the left upper pulmonary vein (LUPV) at or near its insertion site into the LA should be measured, alongside peak systolic and diastolic pulmonary vein flow using pulse-wave Doppler. MV anatomy, severity of any mitral regurgitation (MR), and peak mitral E-wave velocity should be determined.

Although multiplanar 2D TOE measurements provide the main modality for pre-operative assessment, the use of 3D TOE provides useful additive information in identifying those with unusual morphology (Figure 3A) or irregular orifices (Figure 3B). Three-dimensional full-volume or zoom-mode data sets are useful to accurately define LAA orifice dimensions in a number of planes and quantify volume, although these can be affected by fast, irregular heart rates when frame rate is adversely affected. Measurements from 2D TOE, 3D TOE, and cardiac computed tomography (CT) do not appear to be interchangeable, and 2D measurements are consistently smaller than those achieved during multiplanar CT reconstruction.

**Peri-procedural echocardiographic assessment**

**General**

Peri-procedural echocardiography is the most important imaging modality and is essential to aid delivery and deployment of the LAA occluder device. The use of fluoroscopic screening alone to guide device placement is insufficient, particularly in cases of complex multilobar LAA anatomy where accurate device positioning can be challenging (Figure 4). The current peri-procedural echocardiographic modality of choice is multiplanar 2D TOE, but intracardiac echocardiography (ICE) using a phased-array system...
with colour Doppler imaging has been proposed as a viable alternative.\textsuperscript{15,16} TOE necessitates the use of general anaesthesia or heavy sedation and a dedicated TOE echocardiographer and anaesthetic team, whereas ICE requires additional femoral venous access and a second transeptal puncture for imaging within the LA. Both ICE and TOE appear equivalent in their ability to determine LAA dimensions,\textsuperscript{17} in confirming the absence of LAA thrombus and in verifying the location and stability of the occluder device post-deployment.\textsuperscript{15} ICE imaging of the LAA has been shown to be optimal from within the LA itself, as the closer proximity of atrial structures to the ICE probe allows the use of a higher ultrasound frequency, which provides higher image resolution without sacrificing depth of ultrasound tissue penetration.\textsuperscript{16} ICE imaging from the proximal pulmonary artery or right ventricular outflow tract can provide better visualization of the distal LAA in cross-section\textsuperscript{15}. This approach avoids a second transeptal puncture, but the probe must be introduced within a long sheath, such as a Mullins Sheath (William Cook, Europe). Imaging from the coronary sinus or right atrium can be suboptimal due to reduced image quality and foreshortening.\textsuperscript{16} The use of real-time 3D TOE may provide additional anatomical information\textsuperscript{12} and improved demonstration of the spatial relationship of atrial structures compared with conventional 2D TOE imaging.\textsuperscript{18}

**Sequence**

(i) Once LA thrombus has been excluded, the size and shape of the LAA should be re-assessed peri-procedurally and combined with angiographic measurements to guide device size selection, using the maximum measurement obtained from multiple views. With the ACP device, care should be taken to size the landing zone of the anchoring lobe, which is

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**Figure 3** (A) Three-dimensional full-volume reconstruction showing a complex left atrial appendage (LAA), with a broad orifice opening almost immediately into a supplementary lobe (LAA 1) before descending in a more usual pattern to two other lobes (LAA 2 and LAA 3). This type of morphology poses a challenge in determining where a device should sit. (B) Three-dimensional live zoom image of an ellipsoid orifice, identified in the long and short axes by the black lines. Three dimensions provide clearer information in this respect than two dimensions.
located at \(\sim 10 \text{ mm}\) into the lobe being sealed. An ACP device cannot be used if the landing zone is \(<10 \text{ mm}\) width.

(ii) Echocardiography is invaluable when guiding the transseptal puncture, in verifying position of the delivery sheath and aiding delivery and deployment of the device at the LAA ostium (Figure 5). The relationship and orientation of the implant to the LAA and LA wall should be assessed, ensuring that the axis of the device is in alignment with the major axis of the LAA. Colour-flow Doppler (with Nyquist limit lowered to suit the low rate of flow at this site) must be used to detect any leaks into the LA (Figure 6A), which may suggest an undersized implant, and stability of the test observed during traction (Figure 6B). A complete seal of the LAA orifice must be confirmed before release. Any interference with surrounding structures resulting in disruption of MV function and pulmonary vein flow (particularly of the LUPV) should be noted prior to final irretrievable device deployment.

(iii) Success of LAA occlusion can be determined peri-procedurally using angiography and echocardiography grading systems (Tables 1 and 2). The echocardiography grading system can also be used to assess the success of occlusion immediately post-procedure and at follow-up, with successful occlusion being defined as Grade 3 or higher.\(^7\)
Finally, screening for any procedural complications relating to transseptal puncture, device deployment, or when testing device stability, such as haemopericardium, thrombus associated with implantation, or device migration or embolization, which was a particular problem with the first-generation WATCHMAN System, should be performed.

Table 1  Angiographic grading of left atrial appendage occlusion

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Severe leak with well-defined flow of dye completely filling the LAA</td>
</tr>
<tr>
<td>2</td>
<td>Moderate leak filling two-thirds of the LAA</td>
</tr>
<tr>
<td>3</td>
<td>Mild leak filling one-third of the LAA</td>
</tr>
<tr>
<td>4</td>
<td>Trace leak/absent leak with barely detectable or undetectable dye flowing into the LAA &lt; 1 mm diameter jet</td>
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</table>

LAA, left atrial appendage.

Table 2  Echocardiography colour Doppler flow grading assessment of device sealing of the left atrial appendage at implantation, post-procedure, and follow-up

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Severe leak with multiple jets of free flow</td>
</tr>
<tr>
<td>2</td>
<td>Moderate leak, &gt;3 mm diameter jet</td>
</tr>
<tr>
<td>3</td>
<td>Mild leak, 1–3 mm diameter jet</td>
</tr>
<tr>
<td>4</td>
<td>Trace leak, &lt;1 mm diameter jet</td>
</tr>
<tr>
<td>5</td>
<td>No leak</td>
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</table>

Successful occlusion is defined as Grade 3 or higher.
The use of peri-procedural echocardiography is summarized in Table 3. A combination of TOE and TTE may be required to exclude haemopericardium as a blood clot may not show as circumferential effusion.

**Amplatz cardiac plug**
With this device, it is essential to make sure that the anchoring lobe sits in the correct landing zone and lies symmetrically within the LAA lumen, not more than 10 mm from the orifice. Deep implantation may be responsible for thrombus formation on the device. The lower end of the lobe is usually just distal to the circumflex coronary artery, which is easily seen at the atrioventricular junction. The disc of the ACP should be seen sealing the LAA orifice, with separation from the lobe and with a concave appearance, indicating that the disc is being pulled towards the orifice by the anchoring lobe. It is important to exclude a leak around the disc on colour Doppler and ensure that all LAA lobes have been isolated from the LA.

New onset MR not due to impingement of the device on the valve may reflect left ventricular dysfunction which could, in theory, be due to compression of the circumflex coronary artery between the lobe and the disc. Attention should be paid to electrocardiographic changes and alteration in lateral ventricular function. New or worsening SEC could also reflect reduced ventricular function.

**WATCHMAN**
The echocardiogram will guide placement of this device close to the LAA orifice, ensuring that this lies symmetrically in the centre and does not protrude out of the LA ostium. It is important to check the device diameter to confirm compression as this is a marker of device stability.

**Echocardiographic follow-up**
TTE is performed prior to discharge specifically to confirm device position and to exclude pericardial effusion and thrombus around the device. This TTE should also confirm normal MV function and exclude left ventricular dysfunction.

Echocardiographic surveillance is currently recommended at 1, 6 months, and annually post-procedure. TOE is the preferred imaging modality, although TTE may rarely be suitable in those individuals with good echocardiographic windows. The implant should be assessed for stability and for evidence of migration, displacement, erosion, or encroachment on surrounding structures, particularly the LUPV and MV. This is suggested by a reduction in diameter of the LUPV at its atrial insertion site compared with baseline, or through detection of turbulent flow. The atrial facing

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**Table 3** Summary of peri-procedural echocardiography

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
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<tbody>
<tr>
<td>Determine size, lobularity, and shape of LAA to guide device size selection</td>
<td></td>
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<tr>
<td>Guide transseptal puncture</td>
<td></td>
</tr>
<tr>
<td>Verify position of delivery sheath in LAA</td>
<td></td>
</tr>
<tr>
<td>Guide delivery and deployment of device at LAA ostium</td>
<td></td>
</tr>
<tr>
<td>Assess position and ensure correct orientation of implant relative to LAA wall</td>
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<tr>
<td>Check for leaks around device using colour Doppler imaging before final deployment</td>
<td></td>
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<tr>
<td>Check for disruption of transmitral flow</td>
<td></td>
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<tr>
<td>Check for disruption of pulmonary vein flow</td>
<td></td>
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<tr>
<td>Grade success of occlusion post-deployment</td>
<td></td>
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<tr>
<td>Check for device migration and instability post-deployment</td>
<td></td>
</tr>
<tr>
<td>Screen for haemopericardium throughout procedure</td>
<td></td>
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<tr>
<td>Check device for evidence of thrombus formation</td>
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</table>

LAA, left atrial appendage.

**Figure 7** Follow-up three-dimensional full-volume reconstruction demonstrating alignment of an ACP device on the left atrial surface, with smooth healing and no attached thrombus.
surface of the device should be assessed for evidence of smooth healing or any thrombus development, which may necessitate pro-longed anticoagulation (Figure 7). Appropriate thrombus formation or fibrosis may be visible within the LAA. The success of LAA occlusion should be graded according to the presence of any leak (Table 1) around the device margins, detected using colour Doppler imaging. Colour Doppler imaging over the interatrial septum should be used to screen for a persistent shunt following transseptal puncture. LA dimensions should be determined and compared with baseline measurements. Follow-up echocardiography is summarized in Table 4.

Concerns were initially raised that device implantation, resulting in clotting and fibrosis within the LAA, might adversely affect LA function and that close proximity of the device to the LUPV and MV could result in LUPV stenosis or impaired mitral leaflet excursion. Although TOE assessment immediately post-implantation of the PLAATO device and at 6-month follow-up shows that this has not occurred in any cases to date, these potential complications remain a theoretical risk, and therefore, assessment of LUPV and MV function is recommended at follow-up.

Conclusions

The prevalence and incidence of AF is increasing due to a larger ageing population. Cardiac emboli in those with non-valvular AF arise predominantly in the LAA. Although warfarin anti-coagulation is effective in reducing embolic events, including stroke, this treatment is not suitable for all. Closure of the LAA to blood flow by transcatheter percutaneous implantation of an occluder device is effective in reducing stroke in those at moderate-high risk. Pre-procedural assessment requires multplanar TOE, with intra-procedural guidance provided either by intracardiac or TOE echocardiography in conjunction with angiography. Post-procedural surveillance is currently recommended at 1, 3, and 12 months by transthoracic or TOE imaging.

Conflict of interest: none declared.

References