

Echocardiography guidance of atrial septal defect closure

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Abstract: Transcatheter procedures offer less invasive approaches allowing rapid recovery and earlier hospital discharge. A number of international guidelines have defined the role of echocardiography spanning diagnosis, detailed anatomical assessment, device sizing and selection, peri-procedure guidance and post device surveillance. This review discusses the role of echocardiography in transcatheter atrial septal defect (ASD) closure. It describes a systematic approach to assessment including the crucial role of three dimensional echo and provides the reader with key information required during device sizing and procedure guidance.

Keywords: Transesophageal echocardiography; atrial septal defects (ASDs); transcatheter closure; three dimensional echocardiography

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Introduction

Continual growth of cardiac interventions, have paralleled advancements in cardiac imaging. Transcatheter procedures offer less invasive approaches allowing rapid recovery and earlier hospital discharge. A number of international guidelines (1-3) have defined the role of echocardiography spanning diagnosis, detailed anatomical assessment, device sizing and selection, peri-procedure guidance and post device surveillance. Its appropriate use has been shown to improve efficiency and safety through reduction in procedure times, radiation exposure and improved early and longer-term outcomes (4). While two-dimensional echocardiography (2D Echo) and fluoroscopy imaging remain essential tools during structural heart interventions, increasingly three-dimensional echocardiography (3D echo) plays a central role. Although intra-cardiac echocardiography (ICE) may offer some potential peri-procedure advantages; however its use remains limited (*Table 1*) (5). Indeed transoesophageal echocardiography (TEE) imaging provides unrivalled multiplane, high-resolution imaging and will be the focus of this article.

Common to all forms of interventional imaging is a precise understanding of

- (I) The morphological phenotypes relating to the structure of interest;
- (II) The key anatomical landmarks that aid spatial orientation, supported by a comprehensive systematic echo protocol;
- (III) Device sizing based on imaging measurements;
- (IV) Specific imaging views required during procedure guidance.

There is no doubt the present era demands delivery of high quality interventional echocardiography to enable continued advancements in this field. This review aims to provide the core knowledge necessary in delivering optimal procedural echo imaging in supporting best clinical outcomes for transcatheter atrial septal defect (ASD) closure.

Morphological phenotypes of atrial septum (AS) defects

The presence of an ASD, whatever the type, is typically suggested by the finding of a dilated and volume overloaded right ventricle during transthoracic echo (TTE) study (see *Figure 1A,B,C*). The differential diagnosis may include tricuspid and pulmonary regurgitation or the presence of a shunt either anomalous pulmonary venous drainage or

Table 1 Intra-cardiac echocardiography (ICE)

Advantages	
(I)	No need for general anaesthesia (GA)
(II)	Reduced procedure times due to avoidance of GA
(III)	Avoidance of additional physician to perform TEE
(IV)	Oesophageal intubation contra-indicated
(V)	Potential advantage for clear imaging of inferior atrial septum
Disadvantages	
(I)	Higher cost for ICE catheters (often > GA cost) unable to re-sterilize and re-use ICE catheters in UK
(II)	Physician training in ICE imaging and probe manipulation
(III)	Interventionist training in ICE imaging
(IV)	Insertion of second venous sheath with potential risk of additional trauma
(V)	Potential provocation of transient atrial arrhythmias
Current uses across Europe	
(I)	PFO and ASD closure
(II)	LAA closure
(III)	Transcatheter aortic valve interventions
(IV)	Electrophysiology procedures
(V)	Paediatric cases

ASD, atrial septal defect. LAA, left atrial appendage; PFO, patent foramen ovale; UK, United Kingdom.

ASD. The ASD may be visualized in three main echo views (see *Figure 1D,E,F*). As part of the assessment other essential findings should be documented, including; concomitant mitral valve (MV) disease (significant disease necessitating surgical repair may be hampered by the presence of a large ASD device) where a surgical approach to repairing both lesions may be more appropriate; dilated left atrium and left ventricle with evidence of diastolic dysfunction; or right ventricular function impairment and evidence of significant pulmonary hypertension; evidence of other congenital lesions [such as bicuspid aortic valve (AV) disease, associated aortopathy, patent ductus arteriosus, ventricular septal defect]. Such findings may alter management in terms of appropriateness of ASD closure or a preferred surgical approach.

Although TTE is often diagnostic, see *Figure 1* (images A-F), TEE is necessary to confirm the anatomy and assess suitability for device closure in most adults, as image

resolution is limited. *Figure 2* gives an overview for the role of the echo modalities in workup of such patients. Four major types of ASD are described and should be distinguished (6), see *Figure 3* (images A, C, E, I). A prerequisite for transcatheter device closure is the presence of adequate rims of tissue bordering the defect. Thus, only secundum ASD (sASD) may be suitable for percutaneous device closure and differ considerably in size, shape, location and number, see *Figure 3* (images C, D, G, I).

The European Society of Cardiology (ESC) Class I indications (7) for secundum atrial septal defects (sASD) closure include presence of a significant shunt (signs of RV volume overload) and when pulmonary vascular resistance is less than 5 Wood Units, where the method of choice is transcatheter device closure whenever possible. See *Table 2* for summary of indications.

Key anatomical landmarks and TEE protocol

Key landmarks are defined by their close proximity to the AS. On the right atrial (RA) side the superior vena cava (SVC), inferior vena cava (IVC), aortic root (Ao) and AV, coronary sinus and tricuspid valve are relevant. While on the left atrial (LA) side the right upper pulmonary vein (RUPV) and MV are important structures (*Figure 4*). A systematic approach to imaging the AS is encouraged (8) to ensure a complete assessment avoids the risk of missing complex anatomy (*Figure 4*). The protocol includes a scout at 0 degrees in transverse plane, imaging the AS through its entire length (high, mid, low esophageal levels allowing a quick overview of the defect) then rotating through 0°–180° preferably in 10°–15° increments where specific rim assessments are viewed at 45°, 90°, 135°. A number of anatomical findings should be recorded as each may impact on device type and size selected. A checklist is provided in *Table 3*. Specific rims of the sASD are measured on 2D imaging, and are defined as a minimum of 5 mm in length (*Figure 4A,B,C,D*). This ensures adequate surrounding septal tissue for a device to anchor. Consideration should be given to the integrity of the rim tissue. Thin flimsy tissue is unlikely to have the strength to hold the device disc despite appearing an adequate length. Traditional teaching allows the aortic rim to be absent since the ASD closure device is able to anchor using both left and right discs by splaying across the aortic root. However, more recently a number of erosions resulting in cardiac perforations have led to caution in such anatomy (9,10). The incidence is low 0.1–0.3% (11), and usually arises within the first 12 months although has

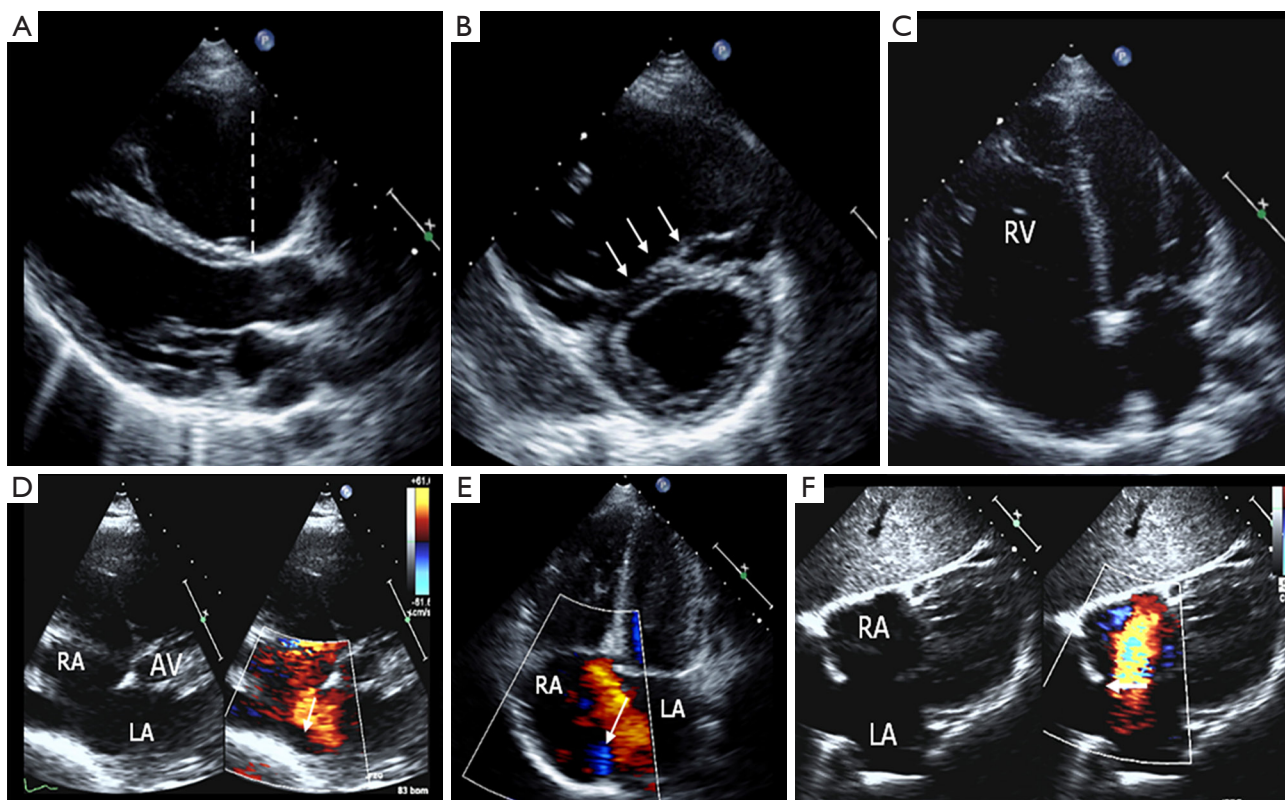


Figure 1 Role of TTE in making the diagnosis. A,B,C demonstrate RV dilation and volume overload state. (A) Parasternal long axis view, dotted line showing a severely dilated proximal RV outflow tract; (B) parasternal short axis view, arrows depict interventricular flattening at end diastole, demonstrating increased RV pressure, which exceeds LV pressure during diastole seen in RV volume overload; (C) apical four chamber view, showing a severely dilated RV. Images (D,E,F) show the parasternal short axis, apical four chamber and subcostal views respectively showing 2D with color Doppler compare across the atrial septum. The white arrows demonstrate the sASD. Sizing the defect is performed using color Doppler to help delineate the margins of the defect to avoid under or over sizing. RA, right atrium; LA, left atrium; AV, aortic valve.

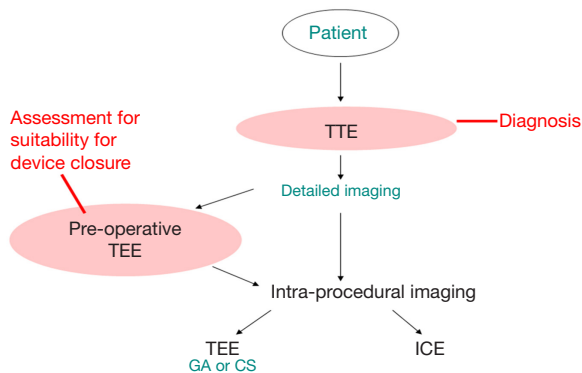


Figure 2 Role of the echo modalities in ASD closure. The initial TTE performed usually demonstrates a dilated right ventricle with a volume overload state and may show the ASD. Following diagnosis or where clarification of the cause of RV dilation is needed, the next step is to perform a TEE. The assessment will include identification of the type, size, location, rims and number of defects to determine suitability for device closure. Finally peri-procedure echo imaging can include TEE or less commonly ICE. The former is usually performed under general anesthesia (GA). Although is some institutions across Europe can be done under conscious sedation (CS). Occasionally is the ASD has been clearly identified and assessed during TTE, detailed anatomical assessment with TOE is performed at the time of ASD closure. TTE, transthoracic echocardiography; TEE, transesophageal echocardiography; ICE, intracardiac echocardiography; GA, general anesthesia; CS, conscious sedation.

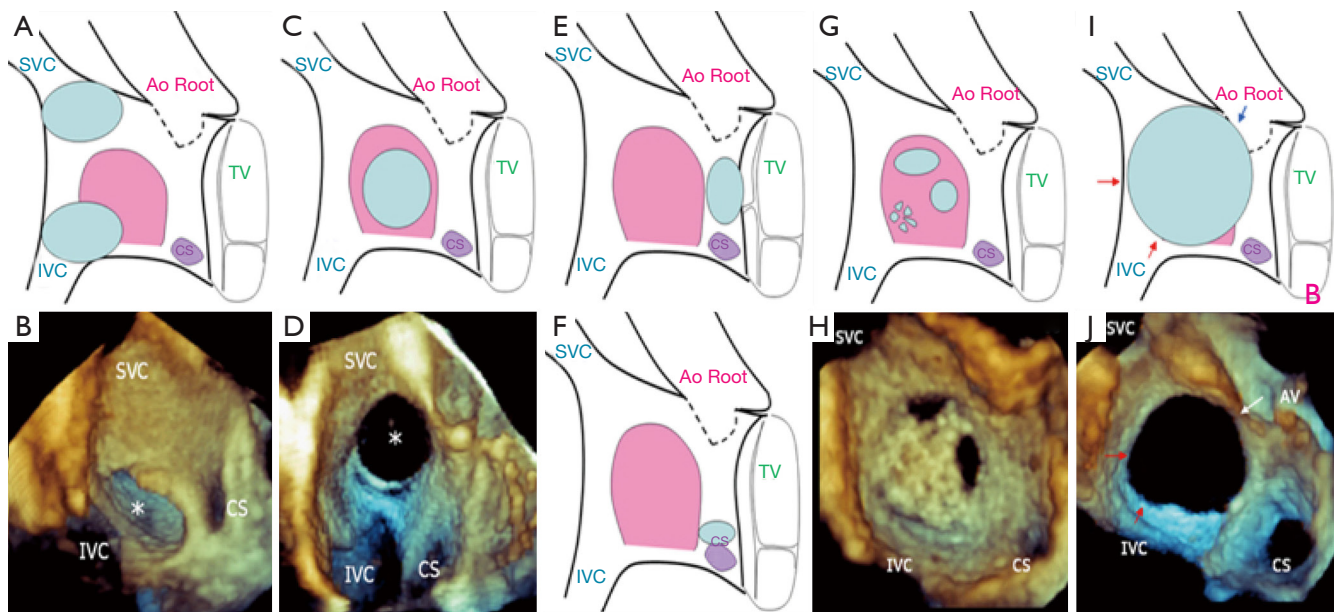


Figure 3 Types of ASD. All viewed from the right atrial side (RA) and each type of ASD is shown in light blue. Where images are available, their corresponding 3D TEE image views are also shown. (A and B) sinus venous defects (in light blue and asterisk) either superior and inferior, named after their position in relation to the SVC or IVC (iSVD), commonly these are associated with anomalous pulmonary venous drainage. (B) depicts a 3D TEE image of the iSVD shown from the RA view. (C and D) depicts a secundum ASD, these defects occupy the FO (septum primum tissue). Primum ASDs form part of an atrioventricular septal defect and are associated with ‘cleft’ atrioventricular valves due to bridging leaflets. The least common ASD type is an unroofed coronary sinus, variable in its extent of absent CS roof tissue, separating it from the LA. (G,H and I,J) show variations in sASD anatomy with their corresponding 3D TEE images. (G) shows 2 discrete defects with associated fenestrations within the inferoposterior FO; its corresponding 3D TEE image, (H) clearly depicts the 2 larger defects, however the fenestrations are not well seen. (I and J) depict a very large sASD occupying most of the atrial septum with limited rims (red, white and blue arrows). SVC, superior vena cava; IVC, inferior vena cava; CS, coronary sinus; Ao, root aortic root; TV, tricuspid valve; FO, fossa ovalis.

Table 2 Indications for percutaneous ASD closure

Suitable for closure

- (I) RV dilatation with or without symptoms with L-R shunt and without significant PAH
- (II) Paradoxical embolism
- (III) Platypnoea-orthodeoxia syndrome
- (IV) Suitable anatomy (adequate rims, defect ≤ 36 mm, LA size allows device, no associated lesions*)

Unsuitable for closure

- (I) Eisenmenger syndrome with R-L shunt, significant PAH unresponsive to PVT
- (II) Current Sepsis
- (III) Contra-indication to anti-platelet therapy
- (IV) Nickel allergy
- (V) Unsuitable anatomy (inadequate rims, defect > 36 mm, LA size too small, associated lesions¹)

Special groups who may be suitable for consideration of balloon occlusion trial

- (I) RV dilatation, significant PAH² but responsive to PVT
- (II) Significant LV impairment, off-loading across ASD which may decompensate once ASD closed

¹, associated cardiac lesions requiring surgery e.g., severe mitral regurgitation, anomalous pulmonary venous drainage; ², pulmonary vascular resistance ≥ 5 wood units, but $<$ two-thirds systemic vascular resistance (or pulmonary arterial pressure $<$ two-thirds systemic pressures) and evidence of left to right shunt where Qp:Qs > 1.5 . ASD, atrial septal defect; PAH, pulmonary arterial hypertension; PVT, pulmonary vasodilator therapy; LV, left ventricle.

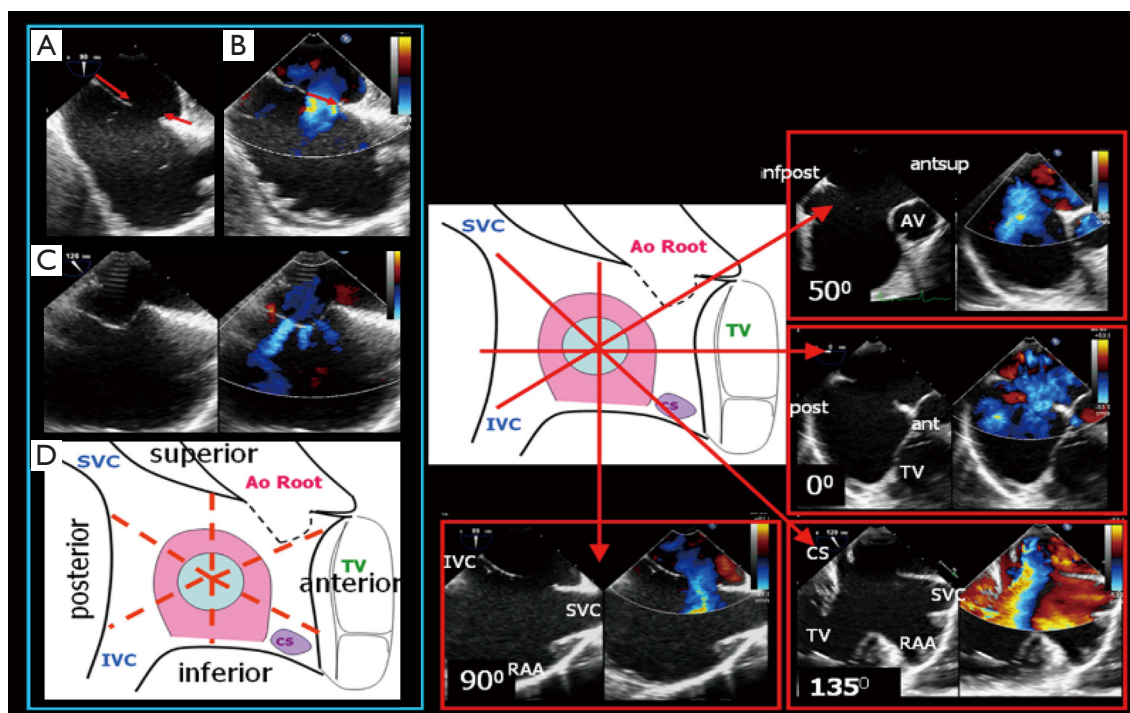


Figure 4 Protocol for assessment of the atrial septum with TEE. All rotation angles are an approximation; the aim is to visualize the rims and structures described. (I) Begin at 0° in transverse plane and sweep high-mid-low by pushing probe up & down and rolling the probe from side to side, allowing evaluation of SVC, posterior, aortic, IVC and CS rims. (II) Rotate probe through 45°–135°, assessing continually size and shape of defect using 2D and 2D CFD. At 90° perform a similar sweep allowing evaluation of SVC and IVC rims. (III) Two further views for measurements of rims performed at 45°, aortic & posterior, and 135°, SVC & IVC rims. The case example demonstrates an absent aortic rim and in regions the posterior rim is <5 mm. This sASD would not be suitable for percutaneous device closure and represents 3D image in *Figure 17* (red and white arrows). (A) Demonstrates measurements of SVC and IVC rims; (B) depicts measurement of ASD using CFD, freeze image and scroll through frames until largest diameter (atrial end diastole) and measure colour jet as shown. This is repeated at 0°, 45°, 90°, 135° giving an understanding of the overall ASD shape; (C) fenestrated FO with multiple small ASD's highlighting importance of CFD assessment; (D) delineates the rims and are described by the structure in close proximity. SVC, superior vena cava; IVC, inferior vena cava; CS, coronary sinus; AV, aortic valve; TV, tricuspid valve; RAA, right atrial appendage.

been reported as late as 8 years post procedure. High risk features appear to include absent or limited aortic and superior vena cava rims (12), compounded by significant device oversizing, and motion ('see-saw' movement) where the waist of the device (or the disc edges protrude into the aortic wall) is in continual contact with the aortic root, perhaps causing distortion of its wall (9,10) (*Figure 5L*). Several discrete defects may necessitate multiple device implantations or fenestrations (multiple small 'pepper pot' defects) may warrant a large device with a narrow waist placed as centrally as possible on the AS to ensure coverage of the entire fossa ovalis (FO).

Device sizing

Sizing the sASD varies between institutions and is dependent on availability and quality of echocardiography imaging offered and preferences of the interventional cardiologist during the procedure. Two major approaches exist, TEE sizing or balloon sizing (BS). 2D TEE provides high-resolution images where the defect measures slightly smaller than the actual size required for device sizing. Colour flow Doppler (CFD) clearly demonstrates flow and the boundaries of the ASD, being comparable to surgical (13) and device sized measurements (14). When

Table 3 TEE checklist for assessing ASD for device closure

Step 1. Confirm defect is secundum type
Step 2. Would surgery be a better option?
Presence of anomalous pulmonary venous drainage
Significant mitral valve pathology necessitating surgical intervention
Step 3. Detailed assessment of defect
Defect size
Number of defects
Surrounding rims
Atrial septal aneurysm
Step 4. Is there a risk for interference during device placement?
Eustachian valve (less commonly Eustachian ridge)
Chiari network

TEE, transoesophageal echocardiography; ASD, atrial septal defect.

the measurements in all four TEE planes [0, 45, 90, 135] are similar (1–2 mm) the largest is taken as the ASD size. If the measurements are significantly different (≥ 3 mm) a mental reconstruction will allow an understanding of the overall 3D shape, although 3D TEE has superseded this requirement, see below. When the defect is circular a single diameter measurement is taken. When oval in shape the short and long axes are averaged and correlate with device sizing. The device size chosen is the measured ASD size plus 20% (15,16). If additional features exist [such as atrial septal aneurysm (ASA) or absent aortic rim] we usually add 25% to the measured size of the defect thereby allowing for adequate grip of the surrounding rims.

Alternatively BS at the time of the procedure is an option. However unless the defect opens (folds back) noticeably once the guide wire is placed, reliance can be placed on echo measurements without the need for BS. If BS is employed then this should be a 'stop-flow' technique (17). This approach ensures sizing in line with TEE avoiding oversizing and its subsequent risks (18). When performed correctly the method relies on TEE imaging. The shaft of the balloon, as it is inflated, is visualized through its entirety (confirming alignment through the central long axis for accurate sizing) and monitored using CFD. When the flow on CFD stops balloon inflation ceases (*Figure 5K*). This method prevents oversizing and a prominent balloon waist is avoided (suggesting over-inflation). The narrowest

central portion of the balloon is measured on TEE and compared to fluoroscopy. The measured diameter equates to the device size. It is recommended not to oversize more than 2 mm in the case of deficient anterosuperior rim due to an increased risk of erosion.

A 3D anatomical understanding of the defect is indispensable when deciding which measurements to include (19). 3D echo provides instantaneous appreciation of defect position, orientation, size and spatial relationships to surrounding structures (20,21) (*Figure 6*), and may offer a superior approach to ASD measurements. Correct anatomical orientation of the 3D image is essential and ideally performed and presented for viewing in a standardised manner. We adopt a similar approach to all 3D echo imaging and like the 'surgical view' of the MV, the AS is presented in an anatomically correct way with clearly defined landmarks (en face LA and RA views, *Figure 6A,B*). Hence a major advantage of 3D echo, is its ability to simultaneously align anatomical understanding between team members (interventional, surgical and imaging) enabling more effective dialogue and an efficiently performed procedure. 3D multi-plane reconstruction allows a detailed assessment of the ASD rims (*Figure 6C,D,E*), simplifying the 2D incremental 10°–15° sweep performed to assess the precise nature of each rim region. Accurate orientation of the 3D defect in its true long and short axis can be rapidly achieved (*Figure 6F*). 3D TEE ASD measurements appear to be more accurate when compared to 2D since they allow precise orientation with the defect axes (22–24). Latest 3D software allows immediate direct measurements to be made from the live 3D image and may make this approach more accessible during procedures.

Procedure guidance

Echo guidance during the procedure optimizes visualisation of the guide wire (and delivery sheath) from the IVC across the defect and into the LA, positioned in the left upper pulmonary vein. Typically this is approximately TEE 45° view. By keeping the delivery sheath in view the device is unsheathed (usually seen towards LA roof) and LA disc is deployed, guided back to and once in apposition to the AS, the RA disc is deployed (*Figure 5A,B,C,D*). A systematic check using the protocol described assesses the device form to ensure it has reshaped to the correct profile, its position on the AS, relationship to surrounding structures and presence of residual flow and its possible cause. CFD reveals flow

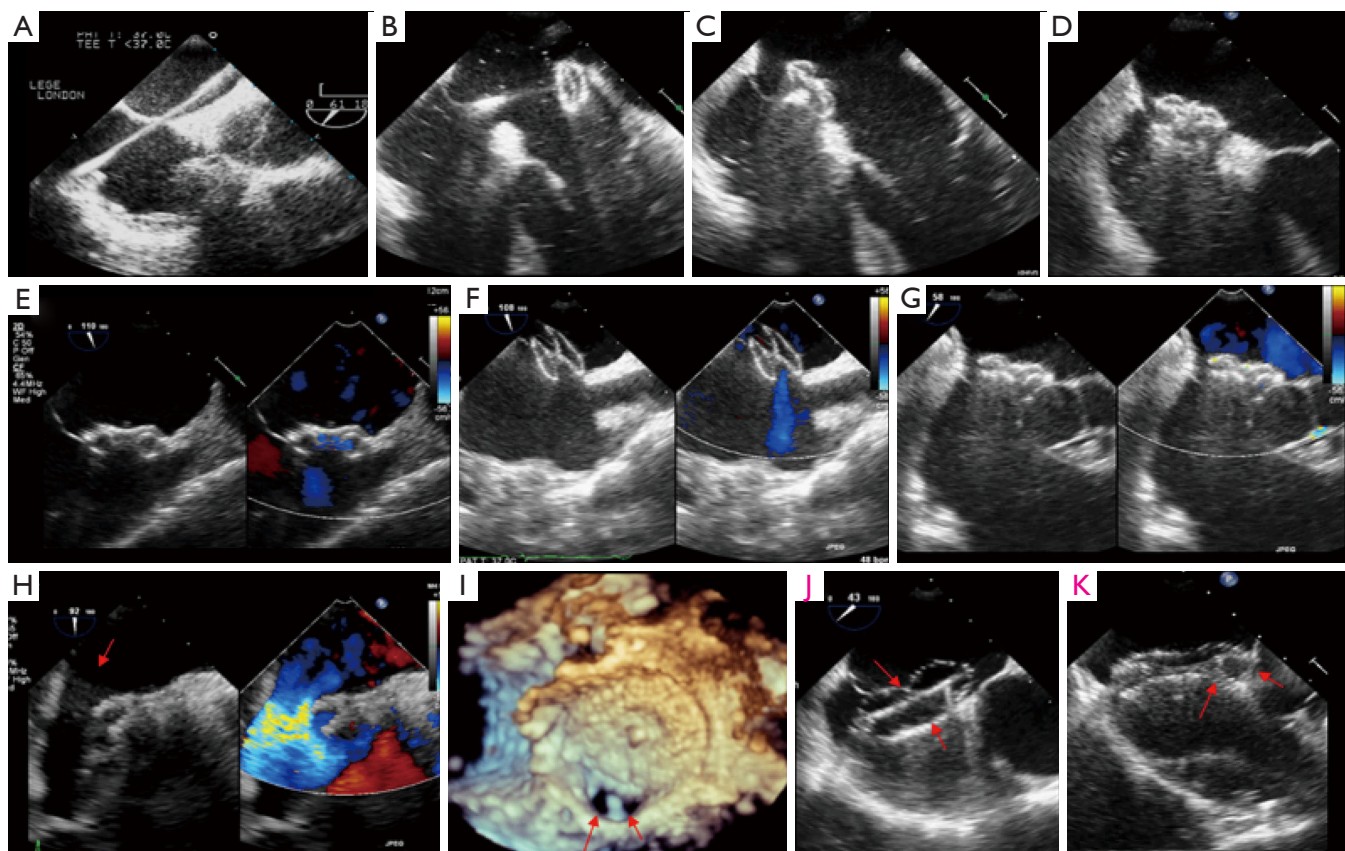


Figure 5 Peri-procedural TEE imaging during device deployment. (A,B,C,D) depict device deployment. A is the ideal image view showing wire passage from IVC, across ASD and into LA, cable length. B shows the unsheathed LA disc of the device. (B and C) depict careful monitoring of LA disc deployment, positioning with correct alignment onto AS, before deployment of RA disc (D). Ensuring AS is captured between discs. (E) shows expected normal flow through the device; (F) flow seen at anterosuperior border when device still attached to cable and under angled tension (importantly no residual flow seen beyond the device discs) and; (G) flow disappears once device released; (H and I) true residual defects following first device placement (red arrows); (J) shows on axis alignment with shaft of inflated balloon; (K) device abuts aortic root, but the waist of the device is not in contact, device does not splay significantly over aorta, and there is not significant cardiac motion in relation to device or distortion of aortic root wall. When these factors are present the risk of erosion and rupture increases.

through the device and is expected (*Figure 5E*). However flow seen around the free edges of the device maybe abnormal and should be assessed systematically to ensure the device has been correctly sized, and no other defects have been unmasked by alterations in AS geometry (*Figure 5F,G,H,I*). 3D TEE gives excellent overview of all these aspects complimenting the information acquired on 2D TEE. Once satisfied the device position and size are correct the device is released and final TEE imaging checks are made repeating the above protocol. Prior to discharge TTE confirms correct device position and excludes pericardial effusion.

Limitations of TEE imaging should be remembered

and include poor echo windows; especially low esophageal views where the inferior border of the AS moves away from the esophageal wall and may be difficult to image. LA size effects the angle of view and ensuring the patient is appropriately volume loaded is essential to optimize the widest angle of view as possible. Where image quality remains poor or esophageal intubation is contra-indicated or where the TEE probe cannot be tolerated (e.g., general anaesthesia not advisable) then ICE imaging may be considered. However referral to a high volume centre with expertise in the use of ICE for ASD closure is advisable if experience is limited.

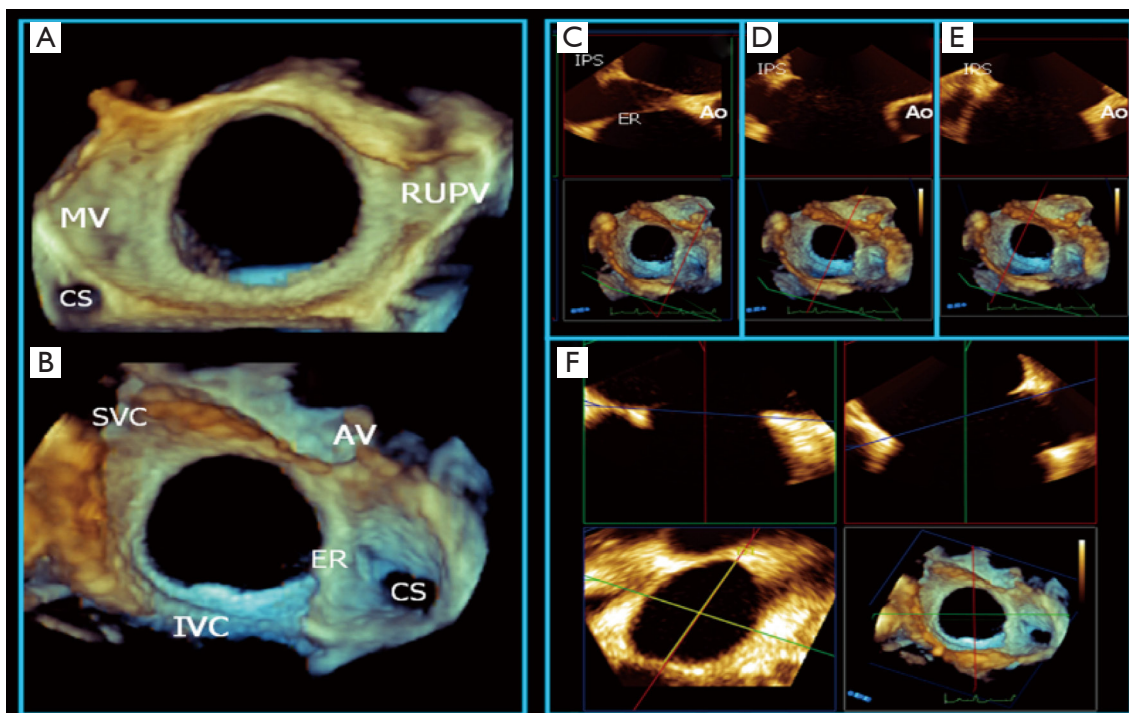


Figure 6 3D TEE utility in the assessment of ASD's. (A and B) show the LA and RA views of the atrial septum respectively. Panels (C,D,E) show multiplanar reconstruction of the same dataset shown in (B). The red plane can be rotated to align with the aortic rim and simply scrolled along the entire rim C to E, giving a complete and rapid assessment. The aortic rim has no septal tissue ('bald' aorta). The process can be repeated for all rims by rotating the plane to the region of focus. This ASD is not suitable for percutaneous closure having absent inferior, posterior and aortic rims. Panel (F), multiplanar alignment to show the long (red) and short (green) axis of the ASD, where measurements can be taken. SVC, superior vena cava; IVC, inferior vena cava; CS, coronary sinus; Ao, proximal aorta; ER, eustachian ridge.

Post-procedure follow up

In our institution follow up is performed at 6 weeks where both a clinical assessment and TTE are performed. If all appears satisfactory (i.e., device position is satisfactory with no residual flow), then a further TTE is performed at six months. Typically the right ventricle has reduced in size to normal or near normal. Tricuspid regurgitation, usually mild or moderate on pre-closure baseline TTE, has improved and is associated with RV and TV annular size reduction. Pulmonary hypertension is less often seen and if noted requires more frequent follow up. If RV has returned to normal size, the device positioned correctly with no or mild TR only then usual follow up is between 2–3 years. At this stage if no issues are found then the patient may be discharged to local follow up. In the case of large devices, where there is concern of potential erosion the patient is counselled regarding the development of concerning

symptoms including chest pain, collapse or palpitations and will be followed up annually.

Conclusions

Transcatheter structural heart interventions afford the benefits of minimally invasive procedures and in the case of the ASD closure is the method of choice. Echocardiography plays a central role in optimizing procedure safety and success through reduced radiation exposure, procedure times and complication rates along with accurate device selection. The addition of 3D TEE imaging has further enhanced our understanding of this procedure. When approached in the manner described above: defining morphological phenotypes, anatomical landmarks, systematic TEE protocol with precise anatomical description and defect sizing, it serves to deliver optimal procedural echo imaging.

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Footnote

Conflicts of Interest: The author has received honoraria for lecturing and providing teaching material to Occlutech Company, Boston Scientific Company Inc. and St. Jude Medical (now Abbott Vascular) Company.

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