Chapter 13
Echocardiography in Structural Cardiac Interventions

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Abstract Echocardiography plays an important role in the assessment of structural heart disease. The work-up for the assessment for structural interventions often requires a combination of both transthoracic (TTE) and transoesophageal (TEE) imaging. Three-dimensional (3D) echocardiography provides added value to traditional two-dimensional (2D) echocardiography, allowing for definition of anatomical and spatial relationships. Echocardiography is portable and easily accessible, whilst avoiding the need for radiation and contrast making it the preferred mode of imaging in the cardiac catheterisation lab.

Keywords Aortic stenosis · Mitral regurgitation · Closure devices

Echocardiography plays an important role in the assessment of structural heart disease. The work-up for the assessment for structural interventions often requires a combination of both transthoracic (TTE) and transoesophageal (TEE) imaging. Three-dimensional (3D) echocardiography provides added value to traditional two-dimensional (2D) echocardiography, allowing for definition of anatomical and spatial relationships.

With the evolution of less invasive transcatheter structural cardiac interventions, there is an increasing need for echocardiographic planning and intraprocedural guidance. As the number and complexity of the devices and therapeutic strategies increase, the role of transoesophageal echocardiography in this setting is becoming ever important. Live 3D imaging intraprocedurally has dramatically transformed the efficiency with which some of these procedures can be performed.

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Transcatheter Aortic Valve Replacement

Transcatheter aortic valve replacement (TAVR) was first performed in France in 2002 for severe aortic stenosis [1]. The PARTNER trial published in 2010 was a game changer showing superiority of TAVR to standard medical therapy for individuals who were not suitable candidates for surgical aortic valve replacement [2]. The AHA/ACC guidelines give a Class I indication for the use of TAVR in individuals who are considered high risk for surgical aortic valve replacement. More recently in 2016, the PARTNER II trial showed non-inferiority of TAVR to surgical aortic valve replacement in intermediate-risk patients [3]. The updated 2017 AHA/ACC guidelines give this a Class IIa recommendation, thus expanding the role of this novel technology [4].

To date, TAVR includes the three generations of balloon-expandable valves, namely, the Edward Sapien, the Edward Sapien XT and the Edward Sapien 3. These are tri-leaflet pericardial bovine valves, mounted within a balloon-expandable cobalt-chromium frame. The Edward Sapien XT is available as a 23, 26 and a 29 mm device, whilst the Edward Sapien 3 is available as a 20, 23, 26 mm and a 29 mm device. The Medtronic CoreValve is a pericardial valve in a self-expanding nitinol frame. The Medtronic CoreValve anchors within the LVOT and ascending aorta. This is available in 23, 26, 29 and 31 mm. This device requires a well-sized ascending aorta to accommodate the broad distal portion of the valve. This device is limited to implantation via a retrograde approach [5]. The Evolut R is the next-generation self-expandable TAVR valve which was first introduced in 2014. It was designed to overcome some of the issues faced with the CoreValve. It has a lower delivery profile and an extended sealing skirt to reduce the incidence of paravalvular leaks. Despite no long-term data, this device appears to show good promise [6].

Echocardiography is the gold standard in the assessment of aortic stenosis (AS). It allows assessment of morphology and severity of disease. The AHA/ACC guidelines classify aortic stenosis as severe when peak velocity is $\geq$4.0 m/s, mean gradient is $\geq$40 mmHg and valve area is <1.0 cm^2. These parameters are however flow dependent, and thus grading the severity of AS should also take into account left ventricular function, coexistence of regurgitant valvular disease and clinical symptoms [7].

Echocardiography can also be helpful in determining anatomical suitability for TAVR by providing information regarding the extent and distribution of calcification, as well as aortic annular dimensions. The aortic annular dimension and area determine prosthesis size, which is ultimately the key to procedural success. The aortic annulus, which was once thought to be circular, has now been well described as more oval shaped from both 3D TEE and CT. As a result, 2D TEE can underestimate the annular dimension. On TEE, the annular dimension is measured in early to mid-systole at the level of the basal attachments of the aortic cusps. It is measured from the trailing edge to leading edge, from the three-chamber view which is often between 110° and 140°. Areas of calcification can often result in overestimation of the annular diameter. 3D TEE can be used to calculate the annular area from the 2D

image. The transverse, sagittal and coronal views are all oriented along the aortic root. The transverse plane is then placed at the level of the hinge points. The orthogonal views are then repeatedly rotated (the turnaround rule) ensuring the hinge points have been transacted accurately. The maximum dimension is often seen in the coronal view with the minimum dimension in the sagittal view (Fig. 13.1 [8]).

More recently however multi-detector CT imaging (MDCT) has become an integral part of the work-up for TAVR. In addition to providing accurate assessment of annular area and perimeter, it also allows visualisation of coronary artery origins and iliofemoral anatomy. A gated cardiac CT is required for imaging of the aortic root, and with an adequately low heart rate, excellent spatial resolution can be achieved with minimal radiation exposure. Although cardiac CT has largely taken over the role of the work-up for sizing of the prosthetic valve, TEE still plays an important role in those in whom adequate CT imaging cannot be obtained such as due to arrhythmia, or in whom cardiac CT cannot be performed due to the risk of contrast-induced nephropathy. 3D TEE annular sizing has been found to correlate well with MDCT sizing [9].

Choosing prosthesis size is dependent on the annular area and perimeter, the extent of calcification around the annulus and the type of valve that is to be used. Marked calcification increases the inherent risk of root rupture, and thus it is prudent that the valve is not significantly oversized. Sizing charts are available for each prosthesis to determine the correct valve size [10]. Undersizing a valve can result in paravalvular aortic regurgitation or embolisation of the valve, whilst oversizing can result in valvar aortic regurgitation or aortic root rupture.

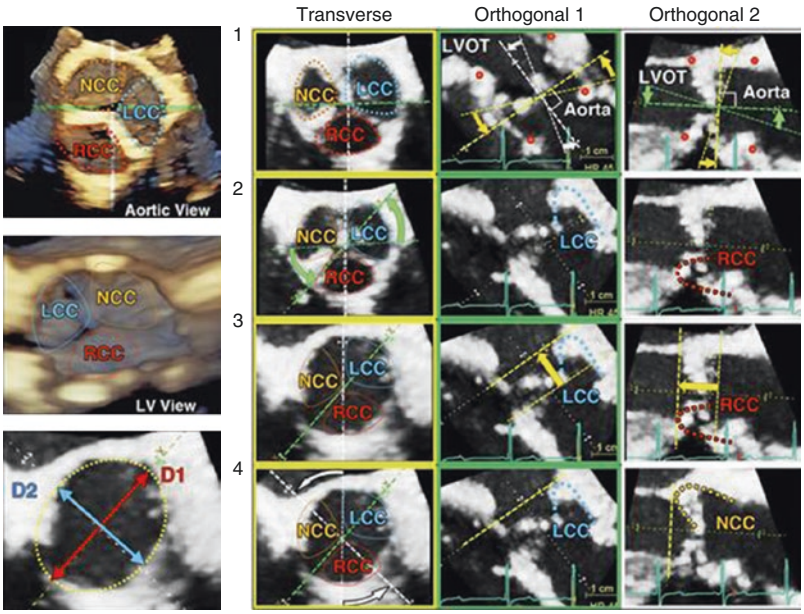

Fig. 13.1 Measuring aortic valve area using 3D multiplanar reconstruction

TAVRs are performed either transaortically or transapically. The transapical approach, which requires a mini thoracotomy, is opted for in patients who have difficult peripheral vascular access and are not amenable to the transaortic technique.

The use of periprocedural TEE can be extremely helpful; however a general anaesthetic is then required for the procedure. Periprocedural TEE has the advantage of providing assistance with balloon dilatation, valve positioning and assessment of valve function immediately after valve deployment and for the early detection of periprocedural complications [11, 12].

The standard TEE working view for guidance during TAVR is generally the three-chamber view for both transfemoral and transapical cases. This view provides the best visualisation of the LVOT, with a clear view of surrounding structures that need to be accounted for during valve deployment, such as the anterior leaflet of the mitral valve. This view is also used to guide the transapical puncture when required as it also provides a view of the true apex and the trajectory needed to reach the aortic valve. TEE can confirm position of the guidewire in the ascending aorta. 3D TEE provides better spatial resolution and allows for optimal balloon positioning. Imaging during balloon inflation ensures that the balloon does not migrate, and in the absence of TEE, this is often done with fluoroscopy. The balloon is prone to migrating in the absence of an adequate landing zone, such as with extensive subaortic septal hypertrophy or a small sinotubular junction. Real-time echocardiography can also be useful when marked areas of ectopic calcification are present to guide safe balloon dilatation (Fig. 13.2).

When assessing valve function following TAVR, imaging of the prosthesis should be performed in multiple views. Mid-oesophageal short- and long-axis views of the aortic valve help confirm valve seating and normal leaflet function. The site and severity of aortic regurgitation should be assessed. Differentiating valvular and paravalvular aortic regurgitation is important. Some degree of aortic regurgitation is not uncommon after TAVR and is often paravalvular. The presence of significant paravalvular aortic regurgitation immediately post valve deployment is due to

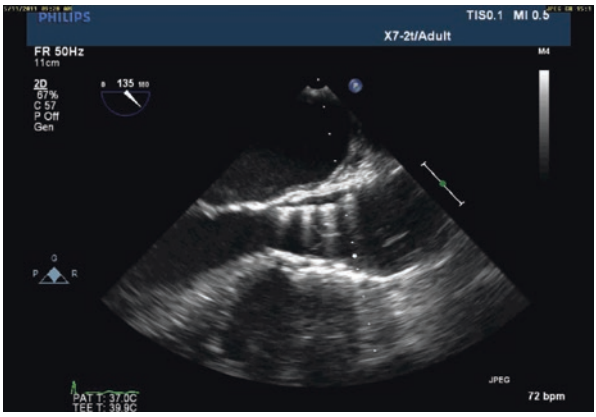

Fig. 13.2 Core valve post deployment

incorrect valve position, suboptimal balloon expansion or an undersized valve. Being aware of this immediately post valve deployment gives the interventionalist the opportunity to further dilate the balloon or deploy a second prosthesis if needed. Oversizing of the prosthesis can result in suboptimal stent expansion, impaired cusp mobility and central aortic regurgitation. There is also a risk of aortic root rupture.

Transgastric view of the aortic valve is useful as it allows Doppler alignment of the aortic valve to determine the gradient across the valve post TAVR. This view can also help identify paravalvular regurgitant jets that may not be well appreciated in the mid-oesophageal view.

3D TEE is useful to help evaluate prosthetic valve function. It can also be a helpful tool to determine the site and severity of aortic regurgitation, especially if the distinction between transvalvular and paravalvular is not clear on 2D.

Early periprocedural complications include aortic rupture and cardiac tamponade. Acute coronary obstruction is exceedingly rare as pre-procedural imaging helps avoid this complication. This can however be a complication if the valve migrates during balloon inflation or deployment. The most commonly described cause for coronary obstruction during TAVI is however displacement of the calcified valve cusp towards the coronary ostia. This can occur in the setting of low coronary height or a small aortic root [13]. The ostia of the coronary arteries can sometimes be appreciated on TEE, though this is not always the case. More commonly left ventricular dysfunction will be seen, and it is important to consider coronary artery occlusion as a possible cause if this is seen. The landing zone of the valve should be at least 10 mm from the coronary ostia [14].

A follow-up echocardiogram is often done prior to hospital discharge. A successful result post TAVR includes a well-positioned prosthesis with a valve area of >1.2 cm^2, a mean gradient of <20 mmHg, a peak velocity of <3 m/s and the absence of moderate or severe aortic regurgitation as moderate or severe aortic regurgitation post TAVR is associated with a twofold increase in all-cause mortality at 1 year [14, 15]. The frequency of follow-up echocardiograms thereafter varies from centre to centre. It is generally recommended that a TTE be performed at 1-, 6- and 12-month follow-up, with an annual TTE thereafter.

Mitral Interventions

Transcatheter mitral valve intervention is an expanding field that has great potential for the future of mitral valve disease. MitraClip technology was approved for use in humans in 2004, for the treatment of mitral regurgitation (MR). The MitraClip device is a 5-mm-wide cobalt-chromium implant with two arms which can be opened and closed using the delivery system handle. The maximal dimension of the device, when the arms are open to 180°, is 20 mm. This technology is designed to create a double-orifice repair, with reestablishment of leaflet coaptation.

The EVEREST II trial published in 2011 found that although percutaneous repair was less effective at reducing mitral regurgitation when compared with

conventional surgery, it was associated with superior safety and similar improvements in clinical outcomes [16]. A sub-study of the EVEREST trial published in 2014 however found that it reduced MR, improved clinical outcomes and decreased LV dimensions at 12 months in an elderly high-risk surgical cohort. Seventy percent of this cohort had functional MR [17].

TTE can be used to determine the severity and the mechanism of the MR. It can also determine suitability of the valve for the MitraClip. TEE can be a useful adjunct when the mechanism of the MR is not clear on TTE; however it is almost always performed for screening purposes when determining anatomical suitability. The severity should be based on a combination of traditional qualitative and quantitative measures. 3D TEE can provide excellent spatial resolution to help determine the mechanism and site of origin of the MR. The MR jet should originate from the central two-thirds of the line of coaptation. As the device creates a double orifice, it is important that there is no pre-existing mitral stenosis. A valve orifice area of >4 cm^2 is ideal. A flail segment width of <1.5 cm and a flail gap of <10 mm are recommended in those with degenerative mitral valve disease. A cleft in the mitral valve or calcified leaflets is a relative contraindication for MitraClip. The MitraClip is not indicated for use in patients with rheumatic heart disease or active infective endocarditis [18] (Fig. 13.3).

TEE guidance is an essential part of this procedure which cannot be performed under fluoroscopy alone. A transseptal puncture is first performed. The site of the

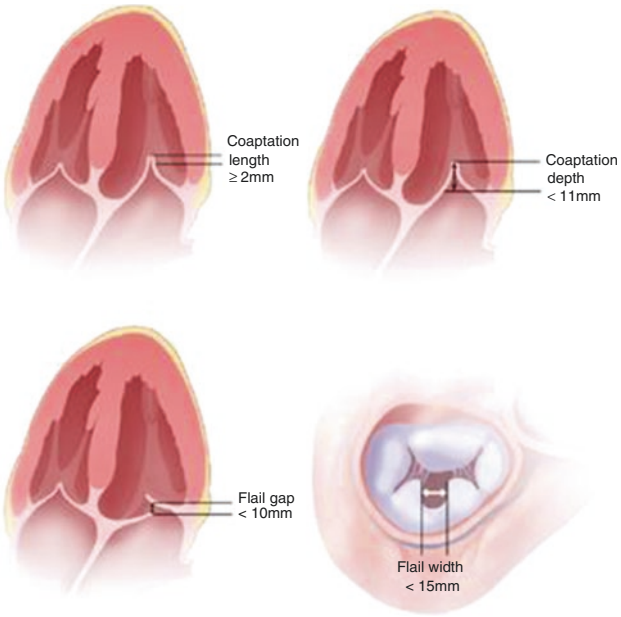

Fig. 13.3 Coaptation length and depth as measured in functional mitral regurgitation. Flail gap and width as measured in degenerative mitral regurgitation

puncture is a crucial step in the procedure. A more supero-posteriorly located puncture is ideal, as it provides adequate space for manipulation of the delivery system within the left atrium to direct it towards the mitral valve. The transseptal puncture should be made approximately 35–40 mm from the level of the mitral valve (Fig. 13.4).

A guidewire is then placed in the left upper pulmonary vein, and the steerable guide catheter advanced over the guidewire. The steerable guide catheter has an echo-bright double ring which can be well appreciated on both 2D and 3D echo. This should lie 2–3 cm within the left atrium. The clip delivery system (CDS) is then advanced through the steerable guide catheter into the left atrium. The arms of the clip are directed perpendicular to the coaptation line of the mitral valve. 3D TEE can be extremely useful in this setting, helping to guide and position the CDS using a bird's-eye view from the left atrial roof (Fig. 13.5).

The device should also be aligned with the origin of the MR jet. It is then advanced approximately 2 cm into the left ventricle. This is usually performed when

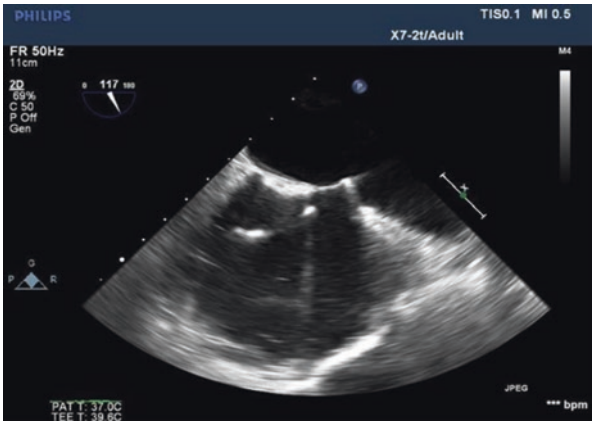

Fig. 13.4 Bicaval view demonstrating tenting of the interatrial septum immediately prior to a transseptal puncture

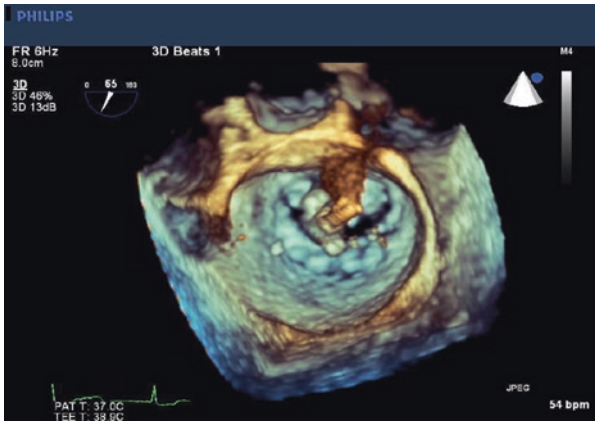

Fig. 13.5 Surgical en face view from the left atrium, look straight down on the mitral valve. The arms of the clip are above the mitral valve and need to be rotated clockwise another 60°, such that they are directly perpendicular to the coaptation line

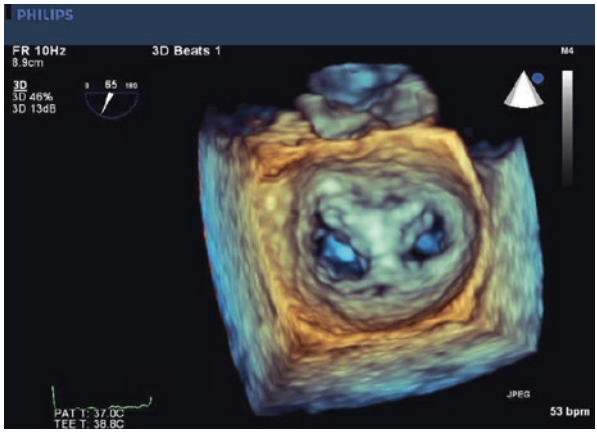

Fig. 13.6 Post MitraClip deployment demonstrating the final result

the device is completely open at 180°. The clip arms are then placed into a grasping position at 120° and pulled back in systole to capture the leaflets. The latter part of this procedure should be done using X-plane, with a bicommissural and LVOT view. This helps to identify the position of the clip from a medial-lateral and anterior-posterior perspective, respectively. It is important there is no tension in the leaflets and that the leaflets move freely above the arms. The MitraClip is then slowly closed and released. Colour Doppler is in fact placed over the mitral valve at various stages of device positioning to gauge the ideal position in which the MR reduction is greatest (Fig. 13.6).

Following the release of the MitraClip, valve function needs to be assessed. The degree of mitral regurgitation should be qualitatively and quantitatively assessed. A reduction in the grade of MR to 2+ or less is the aim of this procedure. A second device may be used to help achieve this. The degree of mitral stenosis (MS) however needs to be assessed prior to this. Quantitative assessment using the mean gradient is a quick and informative means of assessing this. The role of pressure half-time for the assessment of mitral valve area in this scenario is unknown. Planimetry of the mitral valve orifices using 3D MPR can also be very helpful. The degree of mitral stenosis should be taken into account when considering a second clip, as the MR could be reduced at the risk of worsening MS.

An iatrogenic atrial septal defect (IASD) is created following the transseptal puncture. This should be assessed at the end of the study using an X-plane image of the bicaval view, which is at approximately 110°. The size and direction of the shunt should be determined. The persistence of an ASD following a MitraClip procedure is reported in up to 50% of cases. It was associated with a worse clinical outcome and increased mortality [19]. Although there are no clear guidelines as to how to manage iatrogenic ASD's following a MitraClip, closure at the time of index procedure can be considered in the setting of a large right to left shunt associated with pulmonary hypertension or if there are any concerns about systemic embolisation [20].

Transcatheter Paravalvular Leak Closures

Paravalvular leaks are a well-recognised complication following surgical valve replacement, occurring in 5–17% of cases. They are generally more frequently associated with the mitral valve than the aortic valve in this setting [21]. In the era of TAVR, however, the aortic valve too is frequently prone to paravalvular leaks. Postsurgical paravalvular leaks often occur in the setting of significant annular calcification, infection or technical errors that result in incomplete apposition of the sewing ring to the native valve tissue. Paravalvular AR following TAVR was discussed in the earlier segment.

Paravalvular leaks can range from trivial to severe. It is important to distinguish a paravalvular leak from a washing jet, which is a normal finding with mechanical valves. A washing jet is a small jet that arises from between the sewing ring and disc or leaflet. These jets are in theory meant to prevent blood stasis and thrombus formation [22]. Most patients with a paravalvular leak are asymptomatic. Those that are symptomatic, however, often present with congestive heart failure, haemolysis or both. This can sometimes be managed conservatively with medical therapy. Those that are refractory to such therapy however require correction of this leak. Surgical correction requires a repeat sternotomy which carries a significant morbidity and mortality risk. Transcatheter device closure of these leaks has therefore revolutionised the management of these patients. There is a wide range of devices that are used in this setting and are used off-label. The device chosen often depends on the size and shape of the defect. The devices used include Amplatzer and Occlutech. Depending on the leak, more than one device can also be used [23].

The approach to closure of these leaks depends on the valve affected. A mitral paravalvular leak will be antegradely approached via a transseptal puncture in the cardiac catheter lab. Alternative approaches include a retrograde transapical and retrograde transaortic. Aortic paravalvular leaks can be readily approached retrogradely.

Pre-procedural planning is crucial. An initial TTE to identify the severity and origin of the jet is required. A negative TTE however does not exclude a significant paravalvular leak. Acoustic shadowing from calcification and from the mechanical prosthesis can make identification and quantification of the regurgitant jet difficult. Multiple views and off-axis views are recommended to ensure the jet is not being missed.

In those with a high index of suspicion, a TEE is recommended to clarify this. 2D in conjunction with 3D TEE can help quantify and determine the site of regurgitation. Quantification of paravalvular regurgitation is the same as for native valve regurgitation, though this is not well validated. Quantification of paravalvular leaks is difficult even when detected as they are often eccentric, and there are often multiple jets. It is therefore recommended that a combination of multiple qualitative, semi-quantitative and quantitative findings be used to assess the severity of the regurgitation. An additional measurement that is recommended for paravalvular leaks is imaging of the neck of the jet in the short-axis view at the level of the

sewing ring and expressing it as a percentage of the total sewing ring circumference. Thirty percent or greater is considered severe. Greater than 40% valve dehiscence results in rocking of the prosthesis and is therefore associated with severe paravalvular regurgitation [24].

3D TEE can be extremely useful in identifying the exact position and size of the leak. Most mitral paravalvular leaks are crescentic or oblong in shape, rather than being circular. 3D TEE can therefore in this setting provide an accurate measure of the size and shape of the defect. 3D TEE can also provide details of the position of the defect in relation to other anatomical structures. Acoustic shadowing can also occur with TEE, however, and this needs to be taken into consideration. Anterior aortic paravalvular jets are often underdetected or underestimated as a result [25] (Figs. 13.7, 13.8 and 13.9).

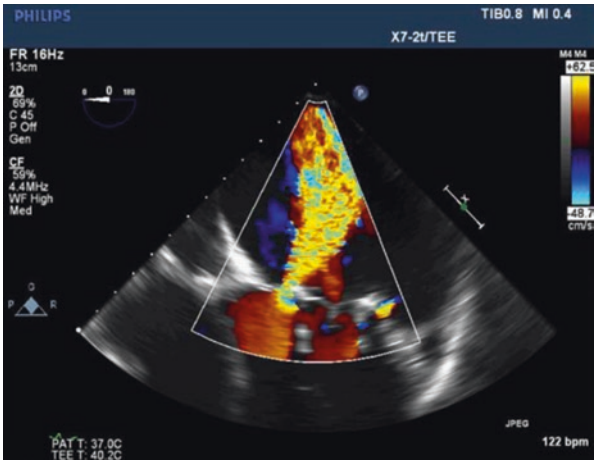

Fig. 13.7 Severe mitral paravalvular leak originating from the medial aspect of the valve

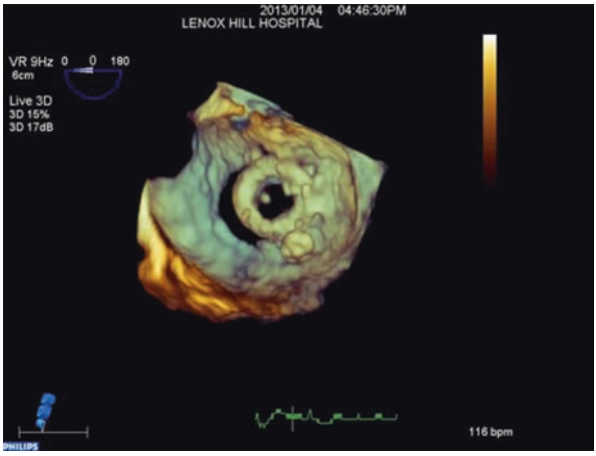

Fig. 13.8 A large defect is seen on 3D at the medial aspect of the sewing ring, extending from 7 o'clock to 11 o'clock

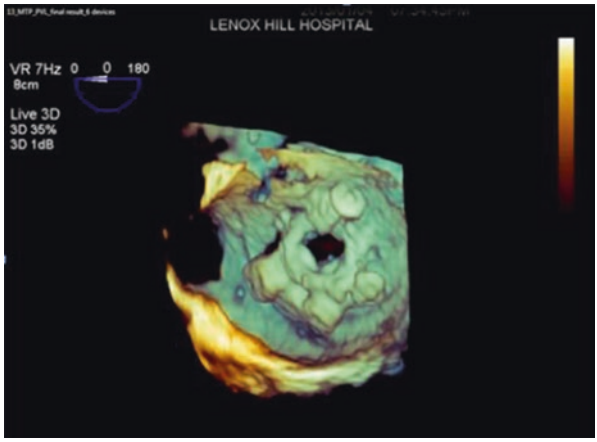

Fig. 13.9 The final result with three new closure devices inserted into the defect

In the setting of a mitral paravalvular leak, the site of transseptal puncture is a crucial aspect of the procedure. An appropriate transseptal puncture site ensures an adequate trajectory directed towards the defect. A medially located paravalvular leak requires a higher puncture on the interatrial septum compared to a laterally located paravalvular leak. Once the left atrium has been accessed, the guide wire is directed towards the defect. The wire can be seen on 2D TEE, but live 3D is extremely useful when it comes to actually directing the wire towards the defect. The en face surgical view from the left atrium visualises the defect from the position of the wire itself, thus enabling the interventionalist to see each incremental movement of the wire. 3D TEE has improved the ease with which these procedures can be performed. Once the wire is passed through the defect, the device is then deployed. It is important to ensure the device is aligned along the correct axis, especially in an irregularly shaped defect. 3D TEE is very useful in this scenario and can confirm appropriate positioning of the device. Colour Doppler can be performed prior to device deployment to confirm the defect is adequately sealed. Once the device is deployed, the device should be interrogated to confirm adequate seating of the device. Colour Doppler should be applied again across the device to assess for residual leak. If a significant residual leak exists, a second device can be considered if it can be safely positioned alongside the first. In some cases, more than one device placement can help stabilise the devices, by anchoring onto each other.

Left Atrial Appendage Device Closures

The left atrial appendage (LAA) is the most common site of thrombus in patients with atrial fibrillation or atrial flutter. Certain LAA morphologies have been shown to have different levels of thromboembolic risk [26]. The LAA can occasionally be seen on TTE, but largely TEE is required for visualisation.

Patients with these arrhythmias who are at a significant risk of cardioembolic stroke are advised to be on an anticoagulant. However, anticoagulants are not without risk, and there remains a small proportion of patient in whom the risk of bleeding outweighs the benefit of anticoagulation. It is in these individuals in whom closure of the left atrial appendage can be a useful alternative to anticoagulation. Surgical closure of the LAA has mostly been unsuccessful [27]. LAA device closure on the other hand was shown to be non-inferior to warfarin therapy [28].

Three devices are currently designed for this procedure, namely, the Watchman, the Amplatzer Cardiac Plug and the WaveCrest.

TEE imaging of the LAA should be performed from multiple views, namely, 0°, 30°, 45°, 90° and 135°. This enables measurement of the short and long axis. The 135° view often captures the widest diameter, which is deemed the landing zone. The landing zone is measured from the area of the left circumflex coronary artery across the LAA to approximately 1 cm inward from the tip of the ridge separating the LAA and left upper pulmonary vein. The depth of the LAA is measured from the ostium line to the apex. For this procedure, a low transseptal puncture is preferred to allow coaxial alignment with the LAA. Thrombus in the LAA is a contraindication to device closure, as it can be dislodged during device positioning. The device chosen is generally 10–20% larger than the diameter of the landing zone. Ideally the device should not protrude more than 4–7 mm beyond the LAA. No or minimal residual flow should be seen following device deployment. However residual peri-device flow is a common finding on TEE following the use of the Watchman device. The PROTECT AF study however found no difference in thromboembolic risk with the presence of a peri-device leak using the Watchman device [29]. The Amplatzer device tends to have less residual flow (Figs. 13.10 and 13.11).

The Watchman device is made of a nitinol cage with a polyethylene terephthalate membrane covering the surface that faces the left atrium. Fixation barbs are available to attach to the neck of the appendage, to minimise the risk of embolisation. This can be used for a LAA with a landing zone between 17 and 31 mm.

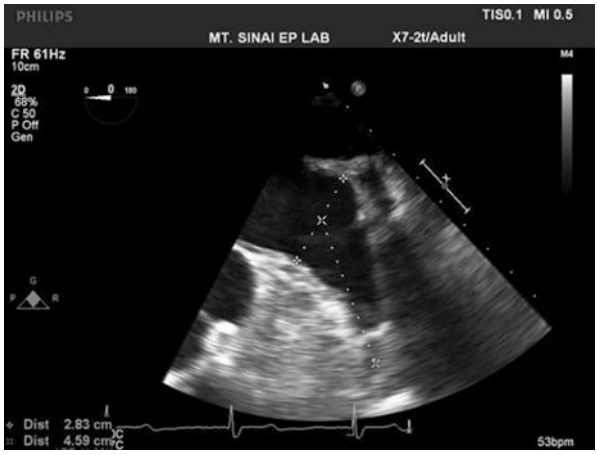

Fig. 13.10 Measurements of the os and height of the left atrial appendage

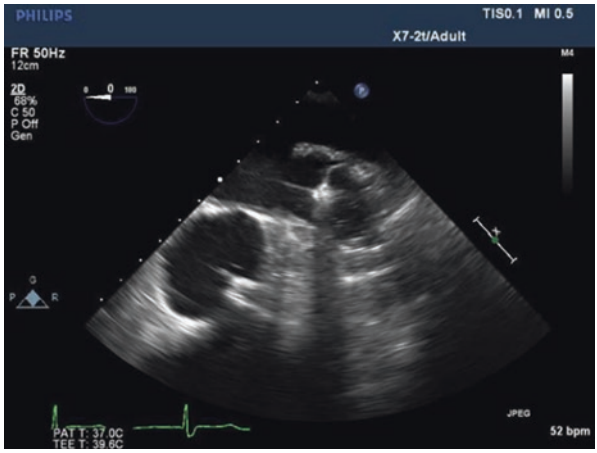

Fig. 13.11 Left atrial appendage device post deployment

The Amplatzer Cardiac Plug (APC) consists of a cylindrical nitinol cage connected by a short flexible waist to a nitinol plate covering the appendage ostium. This device has two discs. This device is shorter than its diameter and is therefore suited for wider appendages. The landing zone should be less than 28 mm for use of the APC. Post deployment, the lobe should be compressed, with an adequate distance to the disc. The disc will develop a slightly concave shape and cover most if not all of the LAA ostium.

The WaveCrest device is made of a nitinol structure with a foam layer that sits within the LAA to promote rapid organisation. The PTFE layer facing the left atrium is designed to reduce thrombus formation. This device sits more proximally within the LAA and is designed for short appendages [30].

Atrial Septal Device Closure

The large majority of secundum atrial septal defects (ASD) can now be closed with a transcatheter device, rather than requiring surgery. The defects however need sufficient rims to be suitable for device closure. TTE can most often help identify the presence of an atrial septal defect, though generally cannot help further delineate the defect. On TTE, the ASD is generally best seen on the subcostal view as the Doppler beam is parallel to flow across the defect. In other views in which the atrial septum is seen on TTE, the interatrial flow is perpendicular to the beam and the septum is subject to artefactual dropout which can falsely give the illusion of a defect. A modified apical view can be used for those with suboptimal subcostal imaging. An agitated saline study is recommended if there is a suspicion of interatrial communication without clear visualisation of the defect itself. The appearance of microbubbles in the left atrium within 3–6 cardiac beats after opacification of the RA confirms the presence of an intracardiac shunt. Provocation manoeuvres such as

the Valsalva are sometimes required to transiently increase right atrial pressure and encourage right atrial opacification [31].

A TEE is recommended for any patient with a secundum ASD who is being considered for device closure. TEE enables assessment of the anteroposterior and superoinferior rims. The interatrial septum should be viewed at multiple angles, starting at 0° to determine the size and location of the defect. It is important to assess the number of defects, as it is not uncommon for more than one defect to be present. The anteroposterior rim refers to the relationship of the defect with the aortic valve and posterior wall, respectively. The superoinferior rim refers to the defects relationship with the SVC and IVC, respectively. 3D TEE can provide a comprehensive assessment of the ASD whilst allowing for measurement of the dimensions and area [32].

The most commonly used device is the Amplatzer septal occluder. This is a double-disc device made from nitinol mesh and polyester fabric. The aortic rim is not uncommonly deficient in secundum ASDs, though it is not an absolute contraindication for device closure. The device can often sit nicely splayed on the aortic valve. There is a risk of erosion in this scenario though it is unlikely especially if the device appears seated well at the conclusion of the procedure. Device closure is contraindicated in the setting of a deficient rim, which is defined as a rim less than 5 mm [28]. Surgical closure is also recommended in the setting of very large defects.

Balloon sizing is generally always recommended. When flow across the defect has completely disappeared, the diameter of the balloon is measured. This is best performed using orthogonal planes on X-plane. This ensures there are no residual defects that have been missed. The device is sized approximately 2 mm larger than the size determined on balloon sizing. 3D TEE however allows for accurate dimensions without the need for balloon sizing. 3D TEE is also very useful during device placement for guiding the delivery system and to ensure appropriate seating of both discs on either side of the septum. At the conclusion of the study, no flow should be seen across the defect. Follow-up can be done with a TTE, which can clearly display the device and confirm appropriate seating [33] (Figs. 13.12 and 13.13).

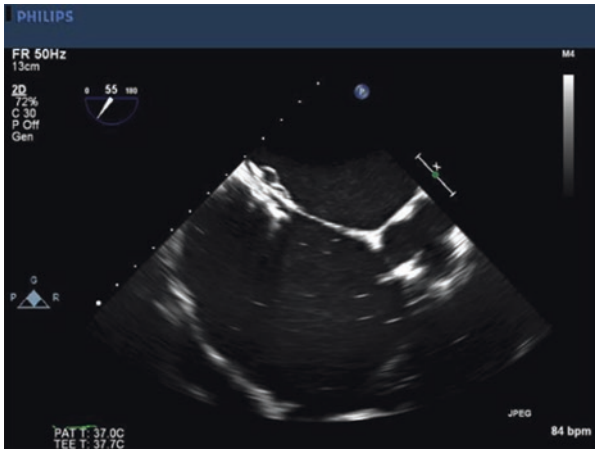

Fig. 13.12 An ASD device is seen well seated on the interatrial septum

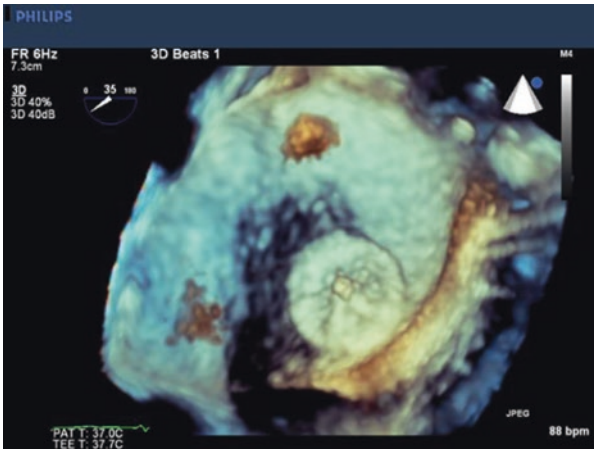

Fig. 13.13 The ASD device as seen on 3D

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