Chapter 4

Advanced Echocardiography for the Diagnosis and Management of Infective Endocarditis

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/64800

Abstract

Echocardiography is fundamental for the management of infective endocarditis (IE) across all stages of the illness including diagnosis, surveillance during medical therapy, identification of prognostic markers, planning perioperative intervention, postoperative assessment, and follow-up after completion of definitive therapy. Modern era echocardiography (echo) offers outstanding temporal and spatial image resolution, providing the opportunity for early diagnosis of this life-threatening infection. Emerging imaging modalities, such as real-time three-dimensional (3D) echocardiography, offer a novel way of readily visualizing the extent of intracardiac infection and the relationship of pathology to adjacent cardiac structures, well before surgical intervention, without radiation exposure or significant risk to the patient. Echocardiography can have a positive impact on the management of every stage of this disease, with the opportunity to improve outcomes.

Keywords: transthoracic echocardiography, transesophageal echocardiography, 3D echocardiography, infective endocarditis, cardiac device-related endocarditis, left-sided endocarditis, right-sided endocarditis, native valve infection, prosthetic valve infection, vegetation, abscess, diagnosis, congenital heart disease, diagnostic accuracy, sensitivity, specificity, management, surgery, cardiac imaging, intracardiac ultrasound

1. Introduction

Echocardiography is fundamental to the diagnosis, risk stratification, management, and follow-up of patients with IE [1]. Modern era transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) enable cardiac anatomy, pathology, and physiology to be assessed in real time. Echocardiography is a readily available, portable imaging modality

that uses the properties of reflected ultrasound waves to construct high-quality two-dimensional (2D) and three-dimensional (3D) images of the heart without radiation exposure. Echocardiography should be utilized at the first opportunity when IE is suspected, to provide an early diagnosis and facilitate important management decisions. However, echocardiographic findings should always be interpreted in their clinical context to maximize diagnostic utility.

This chapter will outline the role echocardiography in the management of IE. In addition, the history of cardiac ultrasound, its diagnostic accuracy, limitations, and emerging technologies such as 3D imaging will be reviewed. Finally, there is a section on imaging protocols and quality control to provide guidance to echocardiography laboratories wishing to pursue excellence in the field.

2. Diagnosis

The modified Duke criteria [2] is used to categorize endocarditis as definite, possible or rejected based on clinical, microbiological, echocardiographic, and pathological findings. Blood cultures and echocardiography are the two key criteria for IE. The modified Duke criteria [2] has an overall sensitivity of ~80–90%, and specificity >90% for diagnosis of IE when compared to pathological diagnosis; however, it is less reliable for identification of prosthetic valve endocarditis (PVE) with sensitivity ~70–80% [3–7]. Transesophageal echocardiography has been shown to improve the diagnostic accuracy of the Duke criteria for definite IE when compared with TTE imaging [8].

A high-clinical suspicion for IE should be adopted especially when fever is present in patients with a prosthetic valve or device, new murmur or heart block, underlying valvular disease or congenital heart disease (CHD), embolism, immunosuppression, previous IE, or intravenous drug abuse (IVDA). It is imperative for early blood cultures be collected prior to antibiotic therapy and urgent echocardiography performed.

2.1. Major Duke echocardiographic findings

The three major echocardiographic findings as defined by the modified Duke criteria [2] suggesting direct evidence of endocardial involvement are vegetation, abscess, and new partial dehiscence of a prosthetic valve.

Vegetation is seen as a high frequency independently oscillating mass typically located on the low-pressure side of cardiac valves, in particular the atrial aspect of the atrioventricular (mitral and tricuspid) valves and the outflow tract side of the semilunar (aortic and pulmonary) valves (**Figure 1**). Less often, vegetations can be sessile with little or no mobility or have mixed sessile and mobile components.

Vegetations are commonly attached along the leaflet coaptation zone, although it can be located anywhere on the valve leaflet, annulus, and subvalvular apparatus. They are also frequently found in the path of abnormal turbulent blood flow ('jet lesion') arising from

http://dx.doi.org/10.5772/64800

valvular regurgitation, a shunt or may spread to adjacent structures by direct contact ('kissing lesion'). Vegetations may also be attached to the endocardial surface lining the heart chambers (mural) or blood vessels (intraluminal). With an aging population and increased cardiac interventions, vegetations involving prosthetic valves, pacing leads, and other non-biological intracardiac materials are becoming more prevalent (**Figure 2**).

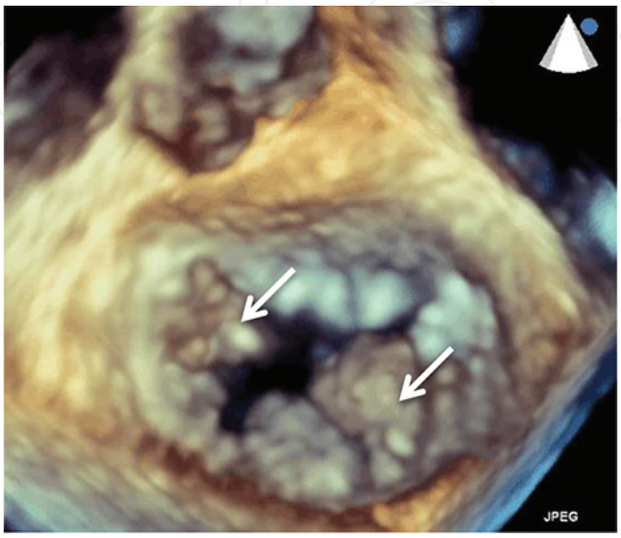

Figure 1. 3D TEE en-face view of mitral valve demonstrating multiple vegetations (arrows).

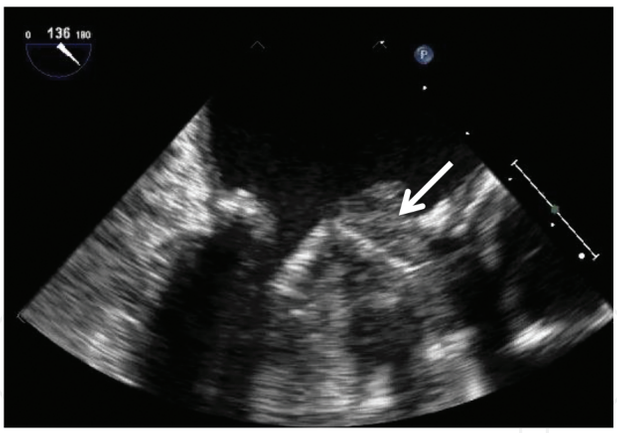

Figure 2. TEE mitral valve with large vegetation causing a 'stuck' anterior mechanical occluder (arrow).

A vegetation has a similar 'gray scale' ultrasound reflectance (echogenicity) to normal myocardium. Chronic 'healed' vegetations, however, often become partly calcified and therefore appear more echogenic when compared to surrounding structures. Vegetations usually have a soft 'shaggy' irregular inhomogeneous appearance on echocardiography helping to differentiate them from simple degenerative valvular tissue strands such as Lambl's excrescences, which tend to be very thin linear structures (**Figure 3**). Vegetations may reduce in size with treatment, embolize, or remain unchanged.

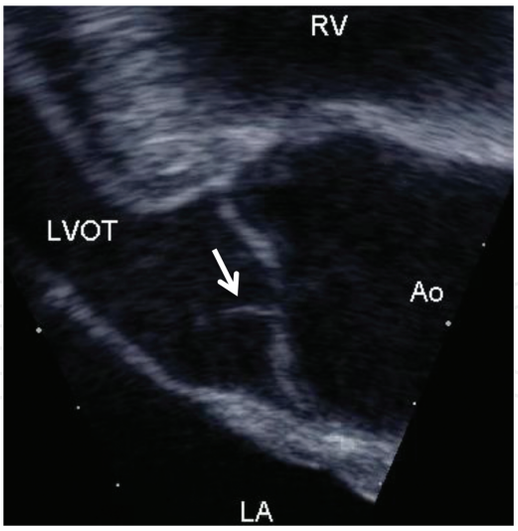

Figure 3. TEE demonstrating the common finding of a degenerative 'Lambl's excrescence' attached to the LVOT aspect (arrow) of the aortic valve.

Differential diagnoses for such masses include fibrin and thrombus, which are frequently extremely difficult, if not impossible to distinguish from vegetations on ultrasound imaging. Other findings, such as pannus and tumors, often have a characteristically distinct appearance from vegetations, albeit subtle, and therefore, it is not always possible to differentiate from one another. While imaging cannot specifically identify the type of microorganism, the appearance/complications of a vegetation may suggest infective agents, for example, fungal vegetations tend to grow to a very large size, and staphylococcus is associated with abscess.

A minority of vegetations are noninfective in origin and referred to as nonbacterial thrombotic endocarditis (NBTE). According to one study [9], lesions resembling NBTE vegetations were identified by echocardiography frequently in patients with antiphospholipid syndrome/Libman–Sacks (63%), myeloproliferative disorders (63%), and solid-organ malignancies (19%). The lesions most often resembled typical vegetations, but also diffuse valve involvement (e.g., **Figure 4**), with a verrucous appearance can occur [9–11].

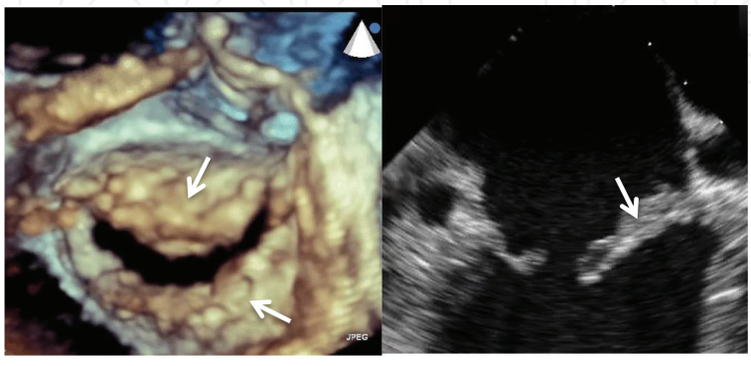

Figure 4. Diffuse, 'verrucous' (arrows) thickening of mitral leaflets in Libman–Sacks endocarditis. Three-dimensional TEE mitral valve (LVOT aspect) and 2D TEE mid esophageal view, mitral valve.

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Intracardiac abscesses appear as inhomogeneous echolucent or occasionally echodense regions, involving the periannular tissue or myocardium, comprised of necrotic and purulent material. A developing abscess may present as a region of periannular thickening (≥10 mm) and is referred to as a *phlegmon*. Importantly, there is no color flow on Doppler imaging into an abscess from the vessel lumen or cardiac chamber.

Abscesses are detected in patients undergoing surgery for endocarditis at the aortic annulus in 33–50% of cases, but only 10–20% are located at the mitral annulus [12–14]. Abscesses account for a higher proportion of complications in PVE (**Figure 5**) and often require surgical intervention [12, 15]. Intervalvular extension of the abscess posteriorly to involve the mitral–aortic intervalvular fibrosa (MAIVF) occurs in approximately two-thirds of aortic periannular infections [16]. In the early stages following aortic valve or root surgery, it may be difficult to distinguish normal postoperative periaortic edema and hematoma from an abscess.

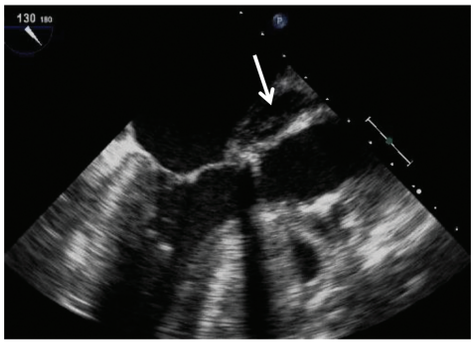

Figure 5. TEE demonstrating posterior periprosthetic aortic abscess (arrow).

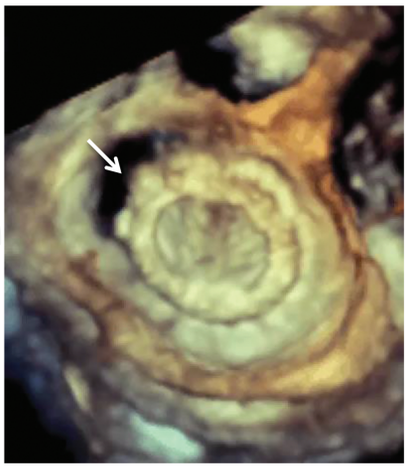

Figure 6. 3D TEE en face of a prosthetic mitral valve with dehiscence at the lateral annulus (arrow).

Mitral annular abscess is often located at the mural annulus, particularly the posterior or lateral annular margin [17], rather than the septal annulus [14]. Mitral annular abscess is more frequently associated with pseudoaneurysm formation and/or fistula than aortic abscess.

Complications include rupture into the coronary sinus, left circumflex artery, or the pericardial space [14]. The presence of mitral annular calcification (MAC), especially caseous calcification, can make diagnosis of annular abscess more challenging due to acoustic shadowing artifact.

New dehiscence of a prosthetic valve occurs when there is disruption of the annular sewing ring due to a breakdown of supporting tissue adjacent to the prosthesis (**Figure 6**). This results in perivalvular regurgitation and may be associated with an abnormal rocking motion. If the area of dehiscence around a bioprosthetic aortic valve is <30%, concordant motion of the valve with the aortic root will occur; however, if >40% of annular area is dehisced, discordant or rocking valvular motion will be present (**Figure 7**) [18].

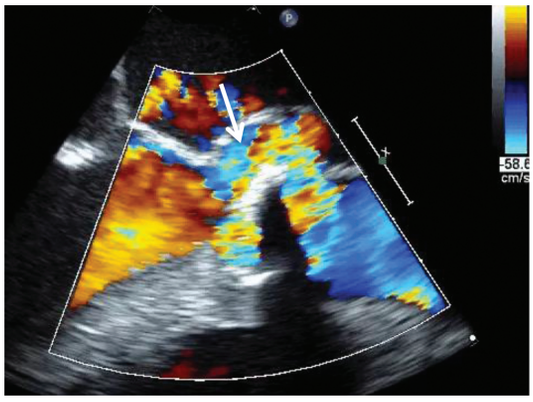

Figure 7. TEE color flow imaging from the 'long-axis' window demonstrating severe periprosthetic aortic valve regurgitation complicating annular dehiscence (arrow). A large region of dehiscence results in a 'rocking' motion of the prosthetic valve.

2.2. Minor Duke echocardiographic findings

Minor echocardiographic findings include but are not limited to perforation, valve aneurysm, fistula, pseudoaneurysm, valve leaflet destruction, and flail leaflet [2].

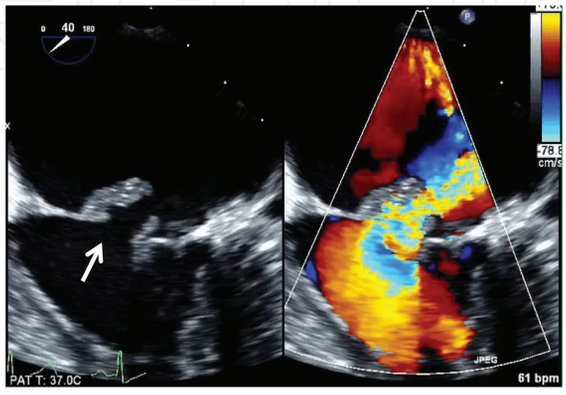

Figure 8. TEE color compare imaging of mitral valve vegetation with perforation (arrow) and severe regurgitation.

http://dx.doi.org/10.5772/64800

The first case report of TEE used to diagnose a perforation was published in 1991 [19]. A perforation is typically a defect through the valvular tissue, separate from the commissures and leaflet margins, well circumscribed and with a 'punched out' appearance on 3D imaging. The finding of a suspected perforation on 2D or 3D echo must be confirmed by demonstrating Doppler color flow traversing the body of the leaflet, typically characterized by flow convergence with a proximal isovelocity surface area (PISA) dome (**Figure 8**).

A valvular aneurysm occurs as a localized bulging sac of the valve leaflet tissue with pulsatile flow seen into the region during systole. The lesion most commonly involves the anterior mitral valve leaflet (AMVL) and usually arises secondary to aortic valve endocarditis [20, 21]. This occurs by either an infected aortic valve regurgitant jet 'seeding' the AMVL or alternatively, from contiguous spread along MAIVF. Localized infection of the mitral leaflet may be followed by valve aneurysm, perforation, and/or leaflet destruction [21].

Cardiac fistula is an uncommon, serious complication, occurring in <1–2.2% [22, 23] of patients with endocarditis and 6–9% of cases when abscess is present [22]. Fistulae often arise from the aortic root or the left ventricular outflow tract [24]. Aortic root fistulas form communications between the aorta and cardiac chambers (aortocavitary) and/or pericardial space (aortopericardial) and often result in hemodynamic compromise. Fistulas can also arise between cardiac chambers [25].

A pseudoaneurysm is defined on echocardiography as an echolucent space communicating with an adjacent cardiac chamber or with the aortic lumen. Blood enters into the cavity under pressure during systole and is seen as pulsatile flow on color Doppler imaging. Pseudoaneurysms frequently arise from the MAIVF with a communication to the left ventricular outflow tract through the narrow 'neck' of the aneurysmal sac [16]. Rupture of a pseudoaneurysm can result in a fistulous connection with the pericardial space, left atrium, or aortic lumen [16, 26].

3. Indications and appropriateness criteria for echocardiography

3.1. American-based guidelines

According to the 2014 ACC/AHA guidelines [27], TTE is indicated in patients with suspected IE to identify vegetations and assess valve hemodynamics, ventricular function, pulmonary pressures, and cardiac complications (class I recommendations). Transesophageal echo is indicated when TTE is nondiagnostic in suspected or known IE, including when intracardiac devices are present and to assess intracardiac complications of IE (class I recommendations). Up to 30% of *Staphylococcus aureus* bacteremia are associated with IE, and therefore, TEE should be strongly considered. In cases where fever defervesced within 72 h and there is a clear extracardiac source (excluding osteomyelitis, spinal involvement, intracardiac device, hemodialysis, structural cardiac disease, prolonged bacteremia, or risk factors), TEE may not be necessary [27].

Another set of independent Guidelines that were published in 2011 by the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria

Working Groups in consultation with other key organizations, developed a scoring system graded from 1 to 9, with 7–9 being an appropriate echo referral, 4–6 uncertain, and 1–3 inappropriate [28]. A summary of the guideline is provided as follows:

3.1.1. Transthoracic imaging

Imaging of native or prosthetic valves is considered most appropriate (grade 9) where endocarditis is clinically suspected and associated with positive blood cultures or a new murmur. In addition, TTE is indicated for reevaluation of IE if any of the following are present as follows: (a) high risk of progressive disease, (b) change in clinical status of the patient, and/or (c) new clinical findings on cardiac examination [28].

Inappropriate reasons for performing TTE include transient fever (without bacteremia or new murmur) and cases of transient bacteremia with a non-IE pathogen and/or documentation of noncardiovascular infection. Also, performing echocardiography for routine surveillance without complications or when findings would not change management, is considered inappropriate and should be avoided [28].

3.1.2. Transesophageal imaging

Appropriateness guidelines for the use of TEE are more generic and are not necessarily specific for endocarditis. The use of TEE is considered reasonable in the following situations: (a) it is anticipated TTE imaging would be suboptimal, (b) to assess for interval change, if it is likely to guide a change in therapy, (c) assess valvular structure for planned interventions, and (d) to diagnose endocarditis if moderate pretest probability in certain subgroups, such as staphylococcal bacteremia or fungemia, prosthetic valves or intracardiac devices [28].

Inappropriate indications include the following: (a) if TTE is likely to be diagnostic, (b) follow-up TEE, when anticipated it would not change therapy, and (c) to diagnose IE with a low pretest probability [28].

3.2. European-based guidelines

The 2015 European Society of Cardiology (ESC) Guidelines on the management of IE provide an alternative set of guidelines on the appropriate use of echocardiography, grouped according to management stage of the illness [17]. A summary of the guideline is provided as follows:

3.2.1. Diagnosis

Class I indications include the following: (a) TTE first line in suspected IE, (b) TEE if negative TTE or nondiagnostic but clinical suspicion of IE, (c) TEE if clinical suspicion of IE if prosthetic valve or cardiac device is present, (d) repeat TTE and/or TEE if initial examination negative but high-clinical suspicion.

Class IIa indications include the following: (a) consider echo for *Staphylococcus aureus* bacteremia and (b) consider TEE in all suspected cases of IE regardless of TTE findings, unless high-quality study of native right-sided uncomplicated infection.

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3.2.2. Follow-up during medical therapy

A class I indication to repeat either TTE and/or TEE is recommended if a new complication is clinically suspected. Consideration to repeat the TTE and/or TEE without complication is given a class IIa indication. The reasoning relates to the possibility of detecting a clinically silent complication and the ability to monitor vegetation size. This class IIa recommendation suggests the frequency of serial imaging should be based on factors such as the initial pathology, type of organism, and the response to treatment.

3.2.3. Intraoperative echocardiography and follow-up after completion of therapy

Class I indications include the following: (a) Each patient should undergo intraoperative echocardiography and (b) follow-up TTE should be performed at the completion of antibiotic therapy.

It is also recommended TTE be performed on a periodic basis along with clinical assessment during the first 12 months following discharge to monitor for the development of heart failure [17]. Consideration should be given to repeat TTE at 1, 3, 6, and 12 months [1].

3.3. Summary of guidelines

The American and European guidelines are similar in most regards; however, the ESC recommendations place emphasis on performing TTE on all patients with suspected IE and suggest consideration be given to progress imaging during the course of treatment, even when there is no change in clinical status. These guidelines are important to provide physicians with direction on the appropriateness of imaging referrals.

4. Important subgroups of endocarditis

4.1. Prosthetic valve endocarditis

Prosthetic valve endocarditis incidence is estimated at 0.3–1.2% per patient-year and accounts for approximately 10–30% of all cases of IE [6, 29]. Infection is classified as early or late PVE (>12 months postsurgery) and is associated with a different microbiological profile [30]. The infection rates are similar for mechanical and bioprosthetic valves, although lower for mitral valve repair [6, 31, 32]. A large multicenter registry study found that the incidence of endocarditis in transcatheter aortic valve implantation (TAVI) was 0.5% by 12 months, with almost half of the patients not surviving to discharge [33].

Mechanical prostheses are prone to periannular complications due to infection of the sewing ring predisposing to abscess, fistula, and/or dehiscence and are more likely to occur within the first few months postsurgery. Bioprosthetic valves primarily seed vegetations on the leaflets which may progress to ulceration, perforation, and/or leaflet destruction [34].

Echocardiographic imaging is more challenging in PVE, particularly with mechanical valves, due to reverberation and acoustic shadowing. Periannular involvement is common and may

be obscured by artifact from the valve prosthesis [34]. Mechanical prosthetic valves are susceptible to formation of adherent thrombus and pannus, while bioprosthetic valves degenerate over time and can develop tissue strands or leaflet tears which can mimic vegetations [35].

Transesophageal echo is superior for assessment and detection of mitral and aortic prosthetic valve abnormalities, including endocarditis, thrombus, and degenerative changes, particularly for mechanical prosthetic valves [36]. Imaging with TTE is limited by the availability of an acoustic window, intervening anatomical structures between the probe and the heart, lower transducer frequency, and acoustic shadowing [36]. Multiplane TEE is highly effective for detecting mechanical valve periprosthetic mitral regurgitation (**Figure 9**), unlike TTE in which acoustic artifact obscures the left atrial aspect of the image [37].

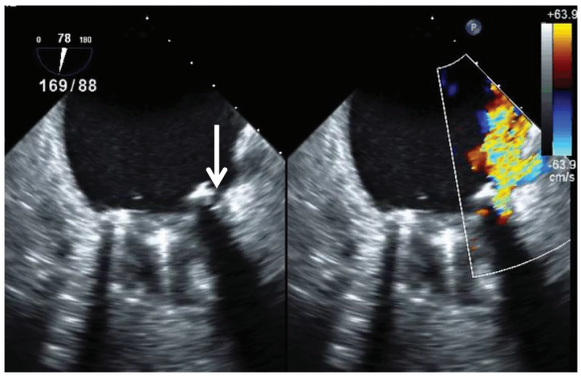

Figure 9. TEE color compare showing prosthetic annular dehiscence (arrow) associated with significant mitral regurgitation.

Although color and spectral Doppler assessment of prosthetic valves should be performed during TTE and TEE examinations, transthoracic echo is preferred for assessment of hemodynamics. In the case of a mechanical prosthetic aortic valve, TTE is also superior when assessing the anterior aortic root for abscess as acoustic shadowing is posteriorly directed obscuring the TEE image.

Aortic and mitral mechanical valve occluder motion is difficult to assess with TTE. The use of 2D and 3D TEE offers excellent assessment of mitral occluder motion; however, it is often suboptimal at visualizing the aortic occluders. The addition of cine fluoroscopy can definitively assess occluder-opening angles, while multidetector-row computed tomography (MDCT) is useful for evaluating occluder motion and identifying any mass lesions [38].

4.2. Right-sided endocarditis

Right-sided endocarditis (RSE) is epidemiologically distinct from left-sided cardiac infection and is associated with a lower mortality, except when vegetations are ≥20 mm [39]. Often vegetations are larger in size nevertheless infrequently associated with periannular extension [40].

The three major subgroups of RSE include IVDAs, cardiac device-related IE (CDRIE), and CHD. A minority of cases do not fit into any category, usually occurring in patients with structurally normal valves and a history of an indwelling venous catheter for treatment of an unrelated medical condition. This group may have a higher risk of periannular complications. In addition, left-sided IE, such as periannular aortic infection, can extend to involve the right-sided cardiac valves [40].

Endocarditis in IVDAs is more frequently associated with fungal and polymicrobial infections, both of which carry a much higher mortality than the expected 5–10% in RSE [39]. Endocarditis in the IVDA group most commonly involves the tricuspid valve with *S. aureus* the usual culprit. Infection rates are higher in HIV-seropositive and HIV-immunosuppressed individuals [40].

4.3. Cardiac device-related infections

Cardiac device-related endocarditis occurs in patients with pacemakers or implantable cardiac defibrillators, which are more prevalent in the older patient cohort. Endocarditis usually involves the presence of vegetations on the device lead, valves, or mural endocardium. Infective endocarditis must be distinguished from localized pocket site infection.

Echocardiography is fundamental for early diagnosis of CDRIE; nonetheless, it can be technically challenging due to artifact shadowing from the pacing leads. Transesophageal imaging is usually required and permits visualization of the leads, venae cavae, and high right atrial wall, which are often difficult to comprehensively investigate with TTE.

Small strands known as accretions are noted incidentally on device leads in approximately 30% of patients without clinical evidence of IE [41, 42]. The lesions appear as thin (1–2 mm) strands or occasionally as fixed small nodular echogenic structures on the leads and are not associated with a poorer prognosis [41].

4.4. Congenital heart disease

The incidence of IE in children is estimated at 0.34–0.64 per 100,000 person years, respectively, approximately ten times less common than in adults. Underlying CHD is found in 11–13% of adults with IE [43]. The most common underlying risk factor in children for endocarditis is CHD, followed by indwelling catheters. Rheumatic heart disease is now rare in developed countries. Only 2–5% of cases of IE occur in children with structurally normal valves compared to 25–45% of adults [44].

The main advantage of TTE over TEE is the need for anesthesia and intubation is avoided [44]. Transesophageal echocardiography should be utilized when TTE is negative but a high-clinical suspicion of IE remains, especially for periannular complications [45]. There are limited data comparing TEE with TTE in adult CHD. Both TTE and TEE may not adequately visualize vegetations or periannular complications associated with prosthetic shunts and conduits. Cardiac CT or MRI could be helpful in this setting [46].

5. Diagnostic accuracy

5.1. M-mode echocardiography

The first moving pictures of the heart using an ultrasound reflectoscope were recorded and published in 1953, by the 'father of echocardiography' Inge Edler, along with physicist Hellmuth Hertz. This led to the development of the standard time–motion (M-mode) ultrasonoscope, which later became known as an echocardiogram and depicted a single-imaging dimension displayed along a time axis [47].

Reference	No. of patients	No. of Vg or valves involved by gold standard*	Sensitivity and specificity for Vg	TTE			TEE			
				NV (%)	PV (%)	PV (%) NV +	NV (%)	PV (%)	NV + PV (%)	
Stafford et al. [53]	*n* = 62	*n* = 29 Sx/path	sens		–	–	93	–	–	–
			spec		–	–	89	–	–	–
Erbel et al. [54]	*n* = 96	AV = 15 MV = 3 PPM = 1 Sx/path	sens		63	–	–	100	–	–
			spec		98	–	–	98	–	–
Mügge et al. [55]	*n* = 105	NV = 69 PV = 22 Sx/path	sens	D	68	27	58	94	77	90
				P	90	36	77	100	86	97
			spec		–	–	–	–	–	–
Daniel et al. [36]	*n* = 126	PV = 33 Sx/path	sens		–	36	–	–	82	–
			spec		–	–	–	–	–	–
Shapiro et al. [56]	*n* = 64	NV+ PV = 30 TTE + TEE	sens		–	–	60	–	–	87
			spec		–	–	–	–	–	–
Lowry et al. [57]	*n* = 93	Clinical ± path (*n* = 29)	sens		50	17	36	100*	83*	93*
			spec		78	94	83	89*	95*	91*
Irani et al. [58]	*n* = 134	*n* = 60# TEE*	sens		68	–	–	–	–	–
			spec		100	–	–	–	–	–

Vg's = vegetations; TTE = transthoracic echocardiography; TEE = transesophageal echocardiography; NV = native valve; PV = prosthetic valve; n = number; Sx = surgery; path = pathological diagnosis, either surgical tissue or at autopsy; AV = aortic valve; MV= mitral valve; PPM = pacemaker lead; sens = sensitivity; spec = specificity; D = definite vegetations seen on echocardiography; P = possible vegetations in addition to definite vegetations seen on echocardiography. *Includes studies using biplane and/or multiplane TEE; # total number included vegetations and/or abscesses detected by TEE

Table 1. Diagnostic accuracy of TTE and TEE for detection of predominantly left-sided cardiac vegetations, pre harmonic era TTE imaging.

The first study to demonstrate vegetations using M-mode echocardiography was published in 1973 [48], followed by a case report of a tricuspid valve vegetation detected in 1974 [49]. Early

work demonstrated M-mode was able to detect approximately one-third of native valve vegetations in patients with a clinical and/or pathological diagnosis of IE [50, 51].

Real-time 2D and 3D echocardiographic imaging, along with color and spectral Doppler capabilities, has superseded M-mode. The culmination of these advancements has enabled echocardiography to emerge as the imaging gold standard for IE and as such, be incorporated into the modified Duke [2] as a major diagnostic criterion. M-mode now contributes little to imaging in IE, except to demonstrate the typical vibrations of vegetations and/or prolapse of valvular tissue with high-temporal resolution (>1000 Hz cf. 30–60 Hz with 2D).

Reference	Gold standard*	Valve type	TEE—number of involved valves or vegetations by location					Sens TTE %	Spec TTE %
			NV	PV	PPM lead	Other site	Total		
Barton et al. [61]	TEE	NV + PV	MV = 50 AV = 34 TV = 19	MV = 16*n* = 11 AV = 25		n = 1	n = 156	58 68#	–
Kini et al. [62]	TEE	NV + PV	n/a	*n* = 51	n/a	n/a	*n* = 179	45	79
Casella et al. [63]	TEE	NV	AV = 21 MV = 15 TV = 2					87 82^	86 62^
Jassal et al. [64]	TEE	NV	AV = 13 MV = 6	–	–	–	*n* = 19	84	88
Chirillo et al. [65]	TEE	NV + PV	AV = 11 MV = 10 TV = 3	AV = 3 MV = 6	–	–	*n* = 33	82 (HI) 36 (FI)	98 (HI) 80 (FI)
Reynolds et al, [66]	TEE	NV	AV=24 MV=26 TV=1	–	*n* = 2	*n* = 2	n=55 (valves, n= 51)	55	–

Vg's = vegetations; TTE = transthoracic echocardiography; TEE = transesophageal echocardiography; NV = native valve; PV = prosthetic valve; n = number; AV = aortic valve; MV= mitral valve; TV = tricuspid valve; n/a = not available; sens = sensitivity; spec = specificity; HI = harmonic imaging; FI = fundamental imaging. *modality against which sensitivity of TTE was compared; ^Included both definite and intermediate likelihood of IE on echocardiography; # sensitivity of TTE for detection of native valve vegetations, excluding prosthetic intracardiac material.

Table 2. Diagnostic accuracy of TTE compared to TEE for detection of predominantly left-sided cardiac vegetations utilizing modern era tissue harmonic imaging.

5.2. Transthoracic echocardiography

In the early 1970s real-time, phased array 2D TTE transducer technology was introduced, providing spatial resolution and anatomical detail not previously seen. This provided not only the ability to identify vegetations like its predecessor M-mode, but to accurately describe the size, point of attachment and morphology of intracardiac masses [52].

5.2.1. Vegetations

During the 1980s and 1990s, numerous landmark studies were published comparing the diagnostic accuracy of TTE for identification of predominantly left-sided cardiac vegetations.

Transthoracic echo was shown to have a combined sensitivity of 36–93% for native and prosthetic valve vegetations and a specificity of 78–100% (**Table 1**).

5.2.1.1. Harmonic tissue imaging

Harmonic sound waves are reflected back to the transducer at twice the frequency of the transmitted wave (fundamental frequency) and are subject to less near-field distortion and side lobe artifact. This results in a better signal-to-noise ratio with superior image resolution [47]. Specifically, there is an improvement in endocardial definition and visualization of the cardiac valves. However, the valve leaflet tissue itself may appear abnormally thickened when viewed using harmonic imaging [59, 60].

A number of studies have revisited the question of diagnostic accuracy of TTE for identification of mostly left-sided native valvular vegetations by comparing findings directly with TEE using modern era tissue harmonic imaging (hTTE). It remains unclear if modern era TTE imaging has resulted in improved detection of vegetations for left-sided vegetations, due to the wide variation in results reported (**Table 2**).

Reference	Gold standard*	No. abscesses confirmed by gold standard*	TEE multi-plane#	Sensitivity & Specificity	TTE			TEE		
					NV	PV	NV +PV	NV	PV	NV + PV
Daniel et al. [67]	Sx	46 (NV + PV)	No	sens	–	–	28	–	–	87
				spec	–	–	99	–	–	95
Aguado et al. [15]	Sx/path	25 (NV) 11 (PV)	No	sens	–	64	81	–	–	–
				spec	–	–	85	–	–	–
Choussat et al. [12]	Sx	64 (NV) 43 (PV)	Yes	sens	33	40	36	75	88	80
				spec	–	–	–	–	–	–
San Román et al. [24]	Sx/path	30 (PV)	Yes	sens	–	–	–	–	90	–
				spec	–	–	–	–	100	–
Cicioni et al. [68]	Sx	29 (NV + PV)	Yes	sens	–	–	38	–	–	93
				spec	–	–	–	–	–	–

TTE = transthoracic echocardiography; TEE = transesophageal echocardiography; NV = native valve; PV = prosthetic valve; sens = sensitivity; spec = specificity; Sx = surgery; path = pathology, either confirmed with surgery or at autopsy. *modality against which sensitivity and specificity of TTE and/or TEE was compared against. #Multiplane TEE probe transducer utilised for imaging in some or all patients in a study.

Table 3. Diagnostic accuracy of TTE and TEE for detection of abscess.

5.2.2. Abscess

Published data on diagnostic accuracy vary widely for abscess detection by TTE. Sensitivity has been reported at 28–81% with specificity 85–100% (**Table 3**). It is uncertain if harmonic imaging has positively impacted on the diagnostic accuracy, with some studies reporting no improvement [65, 68].

5.2.3. Other complications

There are limited studies, generally with small patient cohorts, assessing the diagnostic accuracy of echocardiography for identifying complications other than vegetation and abscess.

Information regarding accuracy of TTE for identifying pseudoaneurysms is sparse, mostly because this pathological finding is often included in with the abscess group. According to one publication, only about one-half of intervalvular pseudoaneurysms were correctly diagnosed by TTE [21].

The sensitivity of TTE is approximately 50% [23] for detection of aorto-cavitary fistulas, but as high as 93% for detecting periannular dehiscence [68]. Detection rates for perforations with TTE range from 45 to 75% [68, 70, 71] and similar for valve aneurysms (38–75%) when compared with TEE as the gold standard [20, 72]. Not surprisingly valve aneurysms are most likely to be missed on TTE when small in size [21, 73].

Reference	Cohort	Number of patients	Gold standard *	Diagnostic sensitivity of imaging modality			
				M-Mode %	2D TTE %	2D TEE %	ICE %
Berger et al. [75]	IVDA	12	Clinical	60	83	–	–
Ginzton et al. [76]	IVDA#	16	Clinical	63	100		–
Klug et al. [77]	CDRIE	52	Clinical ± Sx	–	23	94	–
Cacoub et al. [78]	CDRIE	33	Clinical ± Sx	–	22	96	–
Victor et al. [42]	CDRIE	23	Clinical ± micro	–	30	91	–
Narducci et al. [79]	CDRIE	44	Clinical ('definite'IE group)	–	–	73	100

IVDA = intravenous drug abuse; CDRIE = cardiac device-related infective endocarditis; TTE = transthoracic echocardiography; TEE = transesophageal echocardiography; ICE = intracardiac echocardiography; sens = sensitivity; spec = specificity; Sx = surgery; micro = microbiological diagnosis. *modality against which sensitivity and specificity of echocardiography was compared against; #majority of patient cohort were IVDA

Table 4. Diagnostic accuracy of TTE and TEE for right-sided valvular and cardiac device-related vegetations.

5.2.4. Subgroups of endocarditis

Limited data have been published addressing the sensitivity of TTE in RSE [74]. For tricuspid valve IE, mostly in the IVDA cohort, sensitivity is high at 83–100% [75, 76], while detection rates in CDRIE are poor at 22–30% (**Table 4**). Transthoracic echo may be adequate for isolated native tricuspid valve IE, especially in IVDAs, unless image quality is suboptimal or if clinical suspicion remains despite negative TTE. Transesophageal echo should be utilized if there may be periannular infection, pulmonary, or left-sided valvular involvement or in the presence of an indwelling intravenous catheter [40].

The sensitivity of echocardiography for diagnosis of IE in CHD overall is estimated at 60–80%, but less sensitive if complex pathology is present [46]. In one study, approximately one-third of adult patients with CHD and a clinical diagnosis of IE had negative findings on TTE

and/or TEE and up to 70% of echocardiograms were negative in palliated complex conditions [80].

In young children, TTE is often sufficient to diagnose IE due to superior acoustic windows compared to adults. Transthoracic echo in children with IE has a high rate of detection of vegetations (>90%) when compared with TEE as the gold standard [81].

5.3. Transesophageal echocardiography

Transesophageal echo using monoplane imaging transducers was introduced into clinical practice in the early 1980s. The spatial resolution and utility of 2D TEE has continued to improve with the introduction of biplane and subsequent multiplane TEE transducers along with other advances in probe technology, digital processing, and image display.

5.3.1. Vegetations

During the 1980s and 1990s, with the introduction of monoplane TEE, a number of landmark studies were published comparing the diagnostic accuracy of TEE for identification of vegetations against the gold standard of surgery or pathological findings. Reported sensitivities and specificities of TEE for detection of left-sided vegetations ranged from 94 to 100% and 77 to 95% for native and prosthetic valves, respectively. Specificity was consistently high at >90% (**Table 1**).

A few studies compared monoplane, biplane, and multiplane TEE. Earlier work found marginally higher detection rates of vegetations and/or abscesses, but differences were minimal [82, 83]. Monoplane TEE not only underestimated vegetation size and extent but also was found to be less accurate at detecting small vegetations [83]. Contemporary studies using multiplane imaging report sensitivities >90% [68, 84]. Considering TEE imaging has always demonstrated high sensitivity and specificity for detection of vegetations, it is unclear if multiplane imaging has improved the diagnostic accuracy.

The reported sensitivity of 2D TEE for detection of vegetations in CDRIE ranges from 73 to 96% (**Table 4**) and is also superior over TTE for distinguishing site of attachment, whether valvular or on a lead.

5.3.2. Abscess

Three landmark studies from the 1990s investigated diagnosis of abscess by echocardiography comparing findings with surgery or autopsy. Daniel et al. [67], Choussat et al. [12], and San Román et al. [24] found that the sensitivity of TEE for abscess was 87, 80, and 90%, respectively. However, other studies have reported greater variability, with sensitivities ranging from 48 to 93%. Specificity has consistently remained high at >90% (**Table 3**).

It is unclear whether detection rates for abscesses have improved since the introduction of multiplane TEE. Although more recent studies in **Table 3** utilized biplane and multiplane imaging, the results did not demonstrate a significant improvement in diagnostic accuracy.

5.3.3. Other complications

Similar to TTE, there are limited studies with small patient cohorts assessing the diagnostic accuracy of TEE for identifying the complications of IE, other than vegetation and abscess.

Accurate detection of perforations is relatively high, ranging from 75 to 100% [68, 70, 71]. Transesophageal echo is the imaging modality of choice for identifying valve aneurysms, although sensitivity is unknown [73, 85], while aorto-cavitary fistulas are almost always identified correctly, with a sensitivity of 97–100% [23, 24]. Perivalvular dehiscence can be accurately diagnosed in the majority of cases with a sensitivity of 71–100% [68, 69, 86, 87] and specificity of >90% [69].

5.4. Three-dimensional echocardiography

Three-dimensional TTE and TEE have been part of clinical practice now in excess of 10 years. Over time, equipment has dramatically improved with the latest TEE matrix array transducers composed of up to almost 3000 piezoelectric elements. This leap of technology has been accompanied by improved digital processing power and miniaturization, along with other software and hardware improvements.

Three-dimensional echocardiography provides a choice of acquisition modes including multiplane (X-plane), real-time 'live' 3D, full-volume (stitched or single beat) 3D, zoom 3D and 3D color Doppler. Live 3D and 3D zoom modes are single-beat acquisitions and represent cardiac structure and function in real time. Full-volume acquisitions have the option of 'stitching' sequential volume datasets over a few cardiac cycles, providing a larger field of view. Single-beat full volume is available; however, it is limited by reduced temporal and spatial resolution.

5.4.1. Vegetation

The role of 3D echocardiographic imaging of vegetations is not well studied. A few case reports or small series confirm, as would be expected, that 3D TEE provides better morphological characterization and localization of lesions compared to 2D TEE. Three-dimensional TEE was shown to improve detection of vegetations in some case reports [88–91]; however, small vegetations may theoretically be more reliably detected with 2D due to higher temporal and spatial resolution.

A major benefit of 3D is the ability to visualize the entire valve and annulus in a single beat, enabling identification of eccentrically located vegetations that may otherwise be missed on a standard 2D TEE examination. Also, 3D imaging provides more accurate assessment of vegetation size. In a direct comparison by Berdejo et al. [92], mitral vegetation length of ≥16 mm on 2D and ≥20 mm with 3D best predicted embolic events.

5.4.2. Abscess

There are no published data to reliably estimate the diagnostic accuracy of 3D TTE or TEE for detection of abscess. However, 3D TEE imaging has been shown in case reports to provide

useful additional information regarding the periannular extent of abscess and the relation to surrounding anatomical structures, including the coronary arteries [90, 93].

5.4.3. Other complications

Three-dimensional imaging enables valve perforations to be viewed 'en face' providing precise localization and sizing of any defect, while a small number of case reports indicate a higher detection rate when compared to 2D TEE [94, 95]. One drawback of 3D is artifactual 'dropout', especially with thin valvular tissue and suboptimal gain settings, which can result in false-positive findings. To confirm the finding, the defect should be visualized in systole and diastole and associated with a thickened rim surrounding the perforation [96]. Finally, 3D may assist with surgical planning when repair is contemplated [94, 96].

Three-dimensional TEE has the potential to demonstrate the extent and location of a valve aneurysm with greater accuracy than 2D imaging [97]. Similarly with perivalvular dehiscence, 3D is able to define the anatomic spatial relationship to surrounding structures and accurately define the location, size, and extent of the pathology [93]. One study showed the added benefit of 3D contrast TTE for accurately delineating the size and extent of a left ventricular pseudoaneurysm, when compared to 2D contrast TTE [98].

The role of 3D echo for right-sided IE is restricted to case reports and small case series [99, 100]. Sungur et al. [101] published the first study that compared 3D versus 2D TEE in tricuspid valve endocarditis against the gold standard of surgery. Three-dimensional imaging provided en-face visualization of all three TV leaflets in nine of 10 cases, allowing accurate identification and localization of multiple vegetations. In addition, 3D was able to better characterize vegetation morphology and size. Three-dimensional TEE also identified a tricuspid annular abscess that was missed on 2D TEE imaging. Three-dimensional TEE may add incremental value in localizing vegetations that are partly obscured by reverberation artifact on 2D imaging [99]. Because the right heart is located anteriorly in the chest, 3D TTE is particularly useful and has the potential to provide better imaging of the tricuspid valve.

5.5. Limitations of echocardiography

Echocardiography, especially TTE, has a number of potential limitations due to patient and nonpatient factors. TTE image quality is influenced by body habitus, chest wall deformity, rib space size, and interposing lung tissue. Poor TTE image quality is the main factor accounting for the superior diagnostic accuracy of TEE [54].

Furthermore, the skills of the sonographer and echocardiologist also influence diagnostic accuracy as shown by interobserver variability. Clinical history is important to the reporting echocardiographer but may result in bias with a trade-off between sensitivity and specificity [102, 103].

The ultrasound equipment, machine settings, and transducer frequency all impact on diagnostic accuracy. The limits of image resolution allow detection of vegetations down to 1.5–2 and 3–4 mm, for TEE and TTE, respectively. Not surprisingly, it has been shown that smaller vegetation size reduces the sensitivity of TTE [54, 104].

http://dx.doi.org/10.5772/64800

Mimickers of vegetations are often responsible for false-positive findings. Examples include degenerative valvular tissue, calcification, flail chords, thrombus, tumor, artifact from calcium or prosthetic material, and even normal anatomical variants such as a prominent Eustachian valve. Small thin linear strands are common and are frequently seen on native valves along the leaflet coaptation zone and may be confused with vegetations. Also, small sterile strands are frequently (18–43%) seen on prosthetic valves and are of uncertain significance [105].

The limitations outlined underscore the need to repeat imaging in due course (usually within one week) if the initial TTE and TEE are both negative, but there remains ongoing clinical suspicion of IE.

6. Echocardiographic predictors of prognosis

Embolism occurs in approximately one-quarter to one-half of patients [106, 107] with endocarditis, but the risk is substantially reduced after initiation of antibiotics within the first 1–2 weeks [111, 114]. Large mobile vegetations are associated with more complications. Vegetations >10 mm in length [55, 106, 110] and mobile masses carry the greatest risks of embolism [106, 111, 112].

Vegetations >15 mm and high mobility pose a major risk of systemic embolism [113]. Previous embolism, change in size of vegetations, *S. aureus*, and mitral valve location increase the risk of new embolism [114]. Right-sided vegetations ≥20 mm portend a poor prognosis, with mortality similar to that of left-sided IE [39, 40].

Echocardiography is very useful at identifying important prognostic markers related to extent of infection, cardiac function, and hemodynamics. Predictors of outcome include periannular extension, severe valvular dysfunction, left and right ventricular systolic function, left atrial size, left ventricular size, left ventricular filling pressures, and pulmonary artery pressure [1, 110, 115, 116]. More specifically, in left-sided native valve *S. aureus* endocarditis, an LVEF <40% or presence of abscess independently predicts in-hospital mortality while abscess and leaflet perforation both independently predict 12-month mortality [117].

7. Surgery and the role of echocardiography

Although patients may respond to prolonged antibiotic therapy alone, up to 50% will require surgical intervention [118]. Early surgery within the first week of antimicrobial therapy can improve survival in complicated left-sided IE; however, it may increase the risk of relapse and prosthetic valve dysfunction [119]. Echocardiography is fundamental in identifying important complications and prognostic markers that influence the timing of surgery.

Heart failure and embolism are the leading causes of mortality. Early surgery for left-sided IE is generally indicated in the following circumstances: (a) congestive cardiac failure, (b) periannular extension, for example, abscess and fistula, (c) large vegetations (>30 mm or

possibly >15 mm) or recurrent emboli (>10 mm), (d) difficult to treat organisms such as *S. aureus*, multiresistant microbes, or fungi, (e) prosthetic valve endocarditis especially with Gram-negative, non-HACEK organisms, and (f) persistent sepsis or uncontrolled intracardiac infection including enlarging vegetations, despite appropriate antibiotics [17, 27].

Perioperative pre-pump 2D and 3D TEE provides the surgeon with a comprehensive real-time assessment of the extent of intracardiac pathology and cardiac hemodynamic status immediately prior to the procedure. A decision can be made on the feasibility of repair versus valve replacement and allows planning of the surgical strategy. The postpump TEE assesses cardiac function, hemodynamics, and the adequacy of surgical procedure. In addition, imaging can ensure the heart is appropriately 'de-aired' prior to removal of the cardiac vent. Intraoperative TEE for IE has been shown to positively impact on at least one of these factors in approximately one-third of operations [120].

8. Image optimization

8.1. Two-dimensional echocardiography

Image optimization is particularly important in IE to ensure early diagnosis and accurate identification of complications. Despite advances in TTE imaging quality, TEE still provides superior diagnostic capability. A TEE probe is in close proximity to the heart, with minimal intervening tissues and therefore less attenuation of the ultrasound waves. This allows the use of a higher frequency (5–7.5 MHz) transducer and provides superior spatial resolution.

The same principles of image optimization apply to both TTE and TEE. To obtain superior spatial resolution, select the highest frequency transducer that will maintain adequate depth penetration. Position the focal zone adjacent to the region of interest and adjust depth and sector width to optimize spatial and temporal resolution [47, 121]. Gain, time gain compensation (TGC), and dynamic compression of the gray scale are adjusted to optimize image contrast, while zoom function in real time improves spatial and temporal resolution [122].

8.2. Three-dimensional echocardiography

Three-dimensional image resolution is dependent on the quality of the 2D picture; therefore, optimizing the image prior to changing to 3D mode is essential. Select the imaging plane or acoustic window with the highest resolution. Imaging in the axial plane provides superior resolution (0.5–1 mm) followed by lateral (1.5–2 mm) and finally elevational resolution (2.5–3 mm) [123]. When performing 3D TTE, select the window that transects the structure of interest through the axial and lateral plane such as the parasternal long axis for the mitral valve.

To allow for optimal postprocessing, it is recommended the gain, compensation, and compression be in the midrange, with the TGC adjusted to display a uniform, slightly brighter image [124]. As spatial resolution increases, temporal resolution is reduced and vice versa. This is due to the limited number of scan lines that can be performed in a fixed period of time.

To improve image resolution, narrow the sector width and optimize frequency, compression, and focus [124, 125].

Multibeat 3D volume rendered image acquisition is limited by 'stitching' artifact from respiration and/or arrhythmia [124]. This can be addressed with breath holding and ensuring image acquisition during regular R-R intervals on the ECG.

Cropping of the 3D dataset can be performed en cart prior to image storage or alternatively, offline on a workstation using proprietary software. The 3D data can then be displayed as volume rendered format and surface rendered format or 2D tomographic slices [123].

Finally, the 3D rendered image is rotated and orientated according to convention. The mitral valve from the left atrial perspective (surgeon's view) with the aorta superiorly (12 o'clock), the aortic valve with the right coronary cusp inferiorly (6 o'clock), the tricuspid valve with the interventricular septum inferiorly (6 o'clock), and the pulmonary valve with the anterior cusp superiorly (12 o'clock). The display formats remain the same regardless of whether the valve is viewed from above or below [124].

9. Imaging protocol for infective endocarditis

Imaging for IE requires a methodical approach and follows the same principles for TTE and TEE. All standard TTE and/or TEE transducer positions and views should be obtained with meticulous scrutiny of the cardiac valves and periannular tissues. Use zoom mode to focus on each valve individually to ensure subtle pathology is not overlooked.

It is important to pan through the cardiac valves and adjacent supporting structures using multiple angles and off-axis imaging. This can be achieved with TEE probe manipulation, such as anteflexion, retroflexion, lateral flexion, probe turning, and probe advancement or withdrawal. Careful manipulation of the probe is required to avoid trauma or perforation of the upper gastrointestinal tract. Similarly, the TTE transducer can be angulated, rotated, or repositioned on the chest wall to maximize diagnostic utility.

With the introduction of multiplane TEE, the 2D image can be effortlessly rotated through 180 degrees. Thorough inspection of the valves, with 2D and color flow Doppler, should be undertaken at frequent intervals, as the angle is increased. This is particularly useful for detecting mitral annular complications and/or localized perivalvular regurgitation.

Interrogation of valvular function with color Doppler along with hemodynamic assessment is essential. Attention should be paid to abnormal color flow arising from valves, fistulae, or other shunts. Images along the direction and path of any pathological color flow are used to identify abnormal communications and exclude jet lesions. Assess cardiac chambers for mural vegetations and the vasculature for endarteritis.

Finally, it is imperative to complete a comprehensive echocardiographic study to assess cardiac function, hemodynamics, filling pressures, and pulmonary artery pressure.

Three-dimensional functionalities such as X-plane, real-time, and multibeat 3D should be routinely incorporated, especially for TEE examination of the mitral and aortic valves. Transthoracic 3D of the tricuspid valve is useful for assessing valve anatomy and pathology, particularly in patients with regurgitation associated with pacing leads [126]. For valvular complications of endocarditis, 3D zoom is preferred, providing good spatial and temporal resolution with a single-beat acquisition [123]. However, if assessing extensive perivalvular pathology or ventricular size and function, then change to a wide-angle full-volume 3D multibeat acquisition.

10. Quality control

Leading echocardiography laboratories must ensure that high standards are accomplished both for clinical practice and for scientific research. Recommendations for core laboratories, including quality control guidelines, have been published by the American Society of Echocardiography [108, 127] and European Association of Echocardiography (Cardiovascular Imaging) [128]. Periodic auditing of stored images and reports should be undertaken and reviewed by an experienced physician. Echocardiographic findings of endocarditis should undergo pathological correlation with surgery or a complimentary imaging modality, such as cardiac CT.

For a center to develop excellence in endocarditis management, a dedicated imaging and clinical database should be established for auditing, quality control, and research purposes. Recent guidelines recommend the establishment of a specialized multidisciplinary team at centers with expertise in managing IE [109]. This approach has been demonstrated to reduce mortality by over 50% [129]. The endocarditis team should be engaged early in the management of suspected IE and urgent echocardiography performed.

The lead echocardiologist should have expertise in the field of cardiac infection and provide ongoing education to medical colleagues and sonographers alike to ensure the highest imaging standards are met. When IE is suspected on echo, expert interpretation of the findings should be communicated urgently to the treating team, especially when significant pathology is identified. The echocardiologist is also able to advise of any requirement for a supplemental procedure, such as TEE or CT, and provide recommendations with regard to appropriate follow-up imaging [17, 27, 109, 130].

11. Complimentary imaging modalities and future directions

11.1. Intracardiac echocardiography

Intracardiac echocardiography (ICE) has the potential to provide better image quality than TEE due to its use of higher frequency ultrasound in close proximity to the right-sided cardiac structures. Narducci et al. [79] directly compared the two modalities, with ICE detecting more intracardiac masses than TEE (**Table 4**).

Consider using ICE, particularly in CDRIE where TEE is inconclusive or discordant with clinical findings. Although ICE is considered a safe procedure [131, 132], its routine use is limited by cost. Future applications include the use of 3D ICE and electroanatomic mapping [131].

11.2. Contrast echocardiography

The application of targeted microbubbles and molecular contrast imaging offers promise as an emerging field of research. Contrast agents could be designed to tag certain cellular or molecular markers, such as inflammatory cells or ligands, enabling contrast imaging to detect the presence, location, and extent of the targeted pathology [133].

11.3. Cardiac computed tomography

Multislice CT shows similar diagnostic performance to TEE for detection of large native and prosthetic valve vegetations, valve aneurysm, abscess, and pseudoaneurysm and provides superior anatomical detail relating to the extent of periannular extension and relation to surrounding structures. Vegetations ≤4 mm and small valvular leaflet perforations are not well detected by CT [84, 134–136]. CT is very helpful for imaging the coronary arteries prior to surgery and for detecting extracardiac complications of endocarditis [134]. A major drawback is the exposure to ionizing radiation.

11.4. Positron emission tomography and fusion imaging

There is interest also in nuclear molecular techniques, in particular ^{18}F-fluorodeoxyglucose (FDG) PET/CT or PET/CTA, as a complimentary modality to echocardiography, especially when TEE is negative in the very early stages of infection and clinical suspicion remains high [136, 137]. ^{18}F-FDG is taken up avidly by leukocytes and therefore identifies regions of inflammation. The CT scan provides complimentary anatomical information. The use of PET/CT has been shown to substantially improve the sensitivity and thus diagnostic utility of the modified Duke criteria for diagnosis of both prosthetic valve endocarditis and cardiac device-related infections [138].

11.5. Cardiac magnetic resonance imaging

Contrast cardiac MRI can potentially detect early periannular extension of infection and may also identify vegetations, although with less accuracy [139]. The role of cardiac MRI in this domain remains undefined. MRI is useful for diagnosing cerebral complications of IE [17, 136].

11.6. Molecular imaging

Potential techniques include bioluminescence and radiolabeled antibodies or leukocytes, to target bacteria, biofilms, fibrin, and sites of inflammation. Bioluminescence requires optical imaging, while radiolabeling uses PET, SPECT, or combined modalities [140]. These experimental techniques may have applications such as detection of infected vascular grafts or intracardiac infection [136].

12. Summary

Echocardiography is fundamental in the management of all aspects of endocarditis from diagnosis, identifying complications and prognostic factors through to guiding surgery, and providing follow-up after treatment. Over the past 40 years, since the introduction of M-mode, echocardiography has evolved rapidly, with high-quality 2D and 3D imaging now in routine clinical use. Echocardiography is readily available, cost-effective, and safe, without exposure to ionizing radiation.

Confirming the diagnosis of endocarditis has never been easier with modern era echo; however, mortality remains high, in part due to delayed diagnosis. Maintaining a high-clinical suspicion for IE in at-risk patients must be combined with early referral for echo to ensure prompt diagnosis and institution of appropriate therapy. Formation of an expert multidisciplinary IE team and appropriate use of echocardiography has the potential to save lives and improve patient outcomes.

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