Appropriateness criteria for the use of cardiovascular imaging in heart valve disease in adults: a European Association of Cardiovascular Imaging report of literature review and current practice

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Heart valve disease is common and a major indication for imaging. Echocardiography is the first-line imaging technique for diagnosis, assessment, and serial surveillance. However, other modalities, notably cardiac magnetic resonance imaging and computerized tomography, are used if echocardiographic imaging is suboptimal or to obtain complementary information, particularly to aid risk assessment in individual patients. This review is a summary of current evidence for state-of-the-art clinical practice to inform appropriateness criteria for heart valve disease. It is divided according to common clinical scenarios: detection of valve disease, assessment of the valve and other cardiac structures, risk assessment, screening, and intervention.

Keywords heart valve disease • valve disease detection • valve assessment • other cardiac structures assessment • risk assessment • screening • intervention

Introduction

Heart valve disease (VHD) is common and a major indication for imaging. Echocardiography is the first-line imaging technique for diagnosis, assessment, and serial surveillance. However, other modalities, notably cardiac magnetic resonance imaging (CMR) and computerized tomography (CT), are used if echocardiographic imaging is suboptimal or to obtain complementary information, particularly to aid risk assessment in individual patients.[1]

This review is of cardiovascular imaging in VHD, excluding endocarditis, and excluding the assessment for transcatheter aortic and mitral valve procedures for which reviews already exist.[2,3] It aims to

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Table I Cardiac imaging for valve disease

1. Detection

Echocardiography indicated:

- Likely pathological murmur (not short soft ejection murmur with well-heard second sound)
- Atrial fibrillation
- Breathlessness or chest pain of potentially cardiac origin
- Aortic valve calcification as an incidental finding on chest CT
- First-degree relative with bicuspid aortic valve
- Women presenting to obstetric clinics who originate in countries with a high incidence of rheumatic disease
- High radiation exposure (Hodgkin or left breast cancer)
- High-dose drugs known to cause valve disease (cabergoline, pergolide, phentolamine, fenfluramine, benfluorex)
- Pre-CABG to detect clinically silent MR which may require additional repair
- Conditions known to be associated with valve disease (e.g. Turner's and Marfan syndromes, SLE)

Echocardiography not indicated

- General population screening
- Screening based on age alone
- Low-dose dopamine agonists used for treating microprolactinoma
- Ejection systolic murmur clearly identified as a flow murmur

CT and CMR

These are not indicated for routine detection but incidental aortic valve calcification on CT chest is an under-recognized indication for echocardiography

2. Assessment of valve disease

2.1 Valve assessment

Echocardiography indicated

For assessing valve morphology and haemodynamic performance

Dobutamine stress echocardiography for low gradient, severe AS with reduced LV EF

Low-flow low-gradient aortic stenosis if LV cavity size normal

Stress echocardiography usually with exercise for patients with symptoms despite moderate aortic stenosis

CT indicated

For assessing valve morphology and opening if echo suboptimal and CMR not possible (pacemaker is severe claustrophobia)

Valve calcification if results discrepant on echocardiography especially low-flow normal LV EF

CMR indicated

For valve morphology if echo suboptimal

Better than echocardiography for the pulmonary valve and subpulmonary and branch pulmonary artery stenoses.

For transvalvar forward flow if echo recordings poor

For grading mitral or aortic regurgitation if uncertain on echocardiography or additional quantification required

Better than echocardiography for grading pulmonary regurgitation

Echocardiography not indicated

Dobutamine stress for low-flow normal LV EF aortic stenosis if LV cavity size small

CT/CMR not indicated

If echocardiographic data are consistent with the clinical formulation

2.2 LV and RV response

Echocardiography indicated

For assessing anatomy and function of both LV and RV

CMR indicated

If accurate RV volumes required

2.3 Aorta

Echocardiography indicated

For assessing the aortic root and the proximal ascending aorta if feasible

For detecting coarctation

For serial assessment of a dilated aorta

CT or CMR indicated

At baseline unless echocardiographic images certain

If echocardiographic image quality good repeat as threshold for surgery approaches (CT better as this allows coronary anatomy and an assessment of

continued

aortic calcification)
If echocardiographic imaging suboptimal CMR
3. Risk assessment
Echocardiography indicated
Assesses risk of events in aortic stenosis based on peak transaortic velocity and change in velocity with time (if the decision for surgery is uncertain based on resting measures or before non-cardiac surgery or planned pregnancy).
CMR indicated
No clear clinical role currently but this is likely to develop based on regurgitant volume (in aortic and mitral regurgitation), LV volumes, evidence of fibrosis
4. Surveillance
Echocardiography indicated
Moderate or severe native valve disease
Dilated aorta or high risk of dilatation (e.g. Turner's syndrome, Marfan)
Normally functioning bicuspid aortic valve
Echocardiography not indicated
Aortic valve thickening without stenosis
Tricuspid aortic valve and no more than mild aortic regurgitation
Mild mitral regurgitation with normal valve appearance or mild prolapse and no risk factors (atrial fibrillation, dilated left atrium, age >50)
CT/CMR indicated
Aortic dilatation if echocardiographic imaging suboptimal or region of dilatation beyond echo window
5. Cardiac surgery for valve disease
Pre-operative
Echocardiography indicated
For confirming valve disease and LV and RV response
CT indicated
For coronary angiography, assessment of aortic size and calcification and for mitral annulus calcification before transcatheter mitral valve procedures
CMR indicated
For aorta if CT not needed for angiography, or for viability if myocardial infarction possible/present
Perioperative and on intensive care units
TEE usually indicated, but TTE can sometimes provide useful post-operative information
Post-operative
Echo for post-operative assessment then routine surveillance indicated (Table 3)
Symptoms or signs consistent with dysfunction or infective endocarditis
Before and during pregnancy or before major non-cardiac surgery
CT and CMR not indicated

CMR, cardiac magnetic resonance; CT, computed tomography; LV, left ventricle; RV, right ventricle; TEE, transoesophageal echocardiography; TTE, transthoracic echocardiography. CABJ, coronary artery bypass grafting; MR, mitral regurgitation; SLE, systemic lupus erythematosus.

represent a summary of current evidence for state-of-the-art clinical practice to inform appropriateness criteria for VHD for which indications are summarized in *Table 1*. The document is divided into sections corresponding to common clinical scenarios: detection of valve disease, assessment of the valve and other cardiac structures, risk assessment, screening, and intervention.

Detection of VHD

Investigation of murmur

Murmurs occur in approximately 20–30% of people,[4] but moderate or severe VHD is far less common with a population prevalence of 2.5% in a US meta-analysis[5] and 3.3% in Norway.[6] However at age ≥75, moderate or severe VHD, usually mitral regurgitation or aortic stenosis (AS), is present in 13.2% people in the USA[5] and 18.7% in the UK.[7] A similar prevalence of AS was shown in Scandinavia.[8,9] The finding of a murmur is an indication for transthoracic echocardiography (TTE) unless it is a short ejection systolic murmur with a well-heard second sound in the absence of a family history of bicuspid valve disease and therefore clearly benign.[10,11] Benign systolic flow murmurs in the context of a high flow state (fever, anaemia, and anxiety) do not necessarily require echocardiography but auscultation should be repeated once baseline conditions are re-established. Murmurs are almost universal in pregnancy and can usually be differentiated clinically without the need for echocardiography.[12]

If moderate or severe VHD is detected, there needs to be a mechanism in place for referral to the local valve clinic[13,14] to avoid the risk of not acting on the echocardiographic findings.

CT and CMR are not indicated to investigate a murmur.

Incidental finding

VHD is a common incidental finding on TTE. The EuroHeart failure survey showed VHD in 29% of patients with heart failure[15] and a similar proportion (~30%) occurred in an unselected normal population over the age of 65.[7] An audit of open access TTE[16] showed that the diagnosis was unsuspected in about one-half of those found to have moderate or severe VHD.

Aortic valve calcification is found in around 20% of chest CT examinations,[17,18] but may not be noticed or may be ignored as it is not the clinical focus of the study. Aortic valve calcification on CT is a reasonable indication for TTE.

Valve disease is rarely detected for the first time on CMR.

Screening

VHD is known to be under-detected[5,7] with implications for prognosis for moderate-to-severe disease,[5] so there is an argument for screening high-risk populations. The prevalence of moderate or severe VHD in individuals aged ≥65 is 10–11%.[5,7] However in the OxVALVE study,[7] TTE as the primary screening method detected mild disease in 44% aged ≥65. This risks 'medicalizing' a substantial proportion of the population. Furthermore detecting mild disease does not necessarily affect prognosis.[6] It is unfortunate that the term 'VHD' is used to describe anything from aortic sclerosis to critical AS. Instead initial screening by auscultation should be performed at any visit to a community physician but particularly at routine annual checks, flu-vaccination clinics or well-person clinics for the elderly. This currently occurs more frequently in some European countries than others.[19] TTE should be offered to those with a likely pathological murmur or any murmur associated with a cardiac symptom

TTE screening has been suggested in elderly patients after hip fracture[20,21] as finding significant AS can lead to modifications in anaesthetic technique and perioperative care. However, an abnormal murmur is almost always present so auscultation should be the initial screen. Any patient with a potentially cardiac symptom should also have auscultation.

TTE screening should not be performed in the general population or based on older age alone without a murmur or potentially cardiac symptom. However, populations with a higher than background prevalence of VHD should be offered TTE even in the absence of a murmur:

- Atrial fibrillation since this is associated with valve disease.[7,16] Significant valve disease was found in 12% of open access echocardiograms requested because of atrial fibrillation[16] and in 21% of people with atrial fibrillation in a community screening study.[7]
- Any symptom of potential cardiac origin. It has been suggested[22] that these populations could have a basic echocardiogram with a hand-held device at the community practice and patients with significant abnormalities can be referred for standard echocardiography.
- First-degree relatives with a bicuspid aortic valve since the risk of aortic or aortic valve pathology is at least 10%.[23,24]
- Conditions associated with a known risk of VHD, e.g. Turners syndrome, Marfan syndrome, Systemic Lupus Erythematosus particularly with antiphospholipid antibodies.[25,26]
- Women from regions of the world with a high incidence of rheumatic fever,[27,28] when they register at obstetric clinics. This is because severe mitral stenosis even if asymptomatic poses a significant risk in pregnancy and is likely to require surgery or balloon valvotomy. Mitral stenosis may not reliably be detected by auscultation.
- Before cardiac bypass grafting not only for assessing LV function but also to detect and quantify mitral regurgitation. This may not be clinically obvious and, if present, is likely to lead to modification of the procedure.
- After or during treatment with drugs known to cause valve pathology by interacting with the 5-HT_{2B} receptor to stimulate fibroblast proliferation, e.g. phentolamine, and fenfluramine,[29] cabergoline and pergolide[30] and benfluorex.[31] Low-dose cabergoline used for the treatment of microprolactinomas rarely causes valve pathology[32,33] and should not be an indication for TTE.
- Late after high-dose radiation typically for left-sided breast cancer or after mantle radiotherapy for Hodgkin's lymphoma. Minor valve thickening is seen in 80% cases and significant valve dysfunction develops beyond 10 years.[34]

CT and CMR are not used for screening due to cost, availability, lack of portability, and (for CT) radiation.

Assessment of the valve and other cardiac structures

The valve

TTE is the mainstay for assessing valve morphology to determine the aetiology and to diagnose the haemodynamic severity (*Table 1*).[35–39]

3D echocardiography may be used to better visualize the extent of prolapse in mitral regurgitation[40] or to assess the orifice of the stenotic mitral valve in rheumatic mitral stenosis because this may not be perpendicular to the usual 2D planes.[41] This can be of particular interest in cases after acute haemodynamic changes like valvuloplasty.[42] 3D-derived left ventricular outflow tract cross-sectional area can be used to correct the continuity equation in the assessment of AS if there is a discrepancy between gradient and orifice size data.[43]

Low-dose dobutamine stress echocardiography (DSE) is useful for patients with a low ejection fraction (EF) if low-flow low-gradient AS is suspected by a combination of mean gradient <40 mmHg and effective orifice area <1.0 cm^2 or indexed effective orifice area <0.6 cm^2/m^2.[37,44] It detects evidence of contractile and flow reserve by an increase in LV EF, LV outflow systolic velocity integral or flow by >20%. It also confirms the presence of severe AS by the mean transaortic gradient rising above at least 30 mmHg (ideally >40 mmHg) at any point during dobutamine infusion. Low-dose DSE should also be considered with discrepant orifice area and gradient values in the presence of low flow (SVi < 35 mL/m^2 or systolic flow < 200 mL/s) with preserved EF if the LV cavity size is normal. DSE is not appropriate if the cavity is small because it will cause intraventricular flow acceleration making it impossible to assess the valve. Calcium scoring on CT is an alternative way of differentiating severe from moderate AS[45] in low-flow low-gradient AS and research is progressing well towards drawing up discriminatory values.

Exercise stress echocardiography is indicated for patients with native VHD and symptoms disproportionate to the findings of the assessment at rest. The aim is to assess valve compliance in the presence of valve stenosis and look for a significant increase in regurgitation or for evidence of coexistent coronary disease or for a pathological rise in pulmonary pressure.[46,47] Dobutamine may be used if image quality is suboptimal and particularly if coronary disease is suspected to allow better wall motion analysis.

CT or CMR can be useful for imaging the valve if echocardiographic image quality is suboptimal or additional information is required.[48] CMR is usually more appropriate for assessing valve motion because CT requires additional radiation exposure, unless CMR is not feasible, e.g. those with standard pacemakers or severe claustrophobia. CMR may be especially useful for imaging the pulmonary valve which can be difficult with echocardiography, especially in larger adult patients. CMR is also better than echocardiography for detecting obstruction above and below the valve and defining branch pulmonary stenoses.[49] CT quantification of valve calcification can help identify a higher likelihood of future progression.[50,51]

CMR is also able to quantify velocity and flow volumes across valves which can provide complementary information to echocardiography.[48] Estimation of the severity of aortic regurgitation by echocardiography remains standard[34] but may be difficult in some situations, for example a bicuspid aortic valve with an eccentric regurgitant jet. CMR quantification may then provide useful information, particularly for differentiating moderate from severe aortic regurgitation.[52] It may also provide clarification in patients with mitral regurgitation where doubt exists about the grade on echocardiography.[53] CMR is also better than echocardiography for quantifying pulmonary regurgitation,

Left and right ventricle response

TTE is the mainstay especially for the assessment of LV geometry and both systolic and diastolic function in left-sided valve disease.

Current thresholds for surgery in aortic and mitral regurgitation are based on LV diameters but these may be unreliable. The LV becomes more spherical in severe aortic and mitral regurgitation and a linear dimension may not be representative of the whole LV. For this reason LV volumes should always be assessed by Simpson's method or preferably, when available, by 3D. Although there is little work on volumetric thresholds for surgery, a change in volume can be used to corroborate a change in linear dimension.

CMR has the highest accuracy of all imaging modalities for LV volumes, mass, and functional assessment and can be used where echocardiographic views are suboptimal or additional quantification is required. CMR LV end-diastolic volume has shown an ability to predict the need for surgery in aortic and mitral regurgitation.[52,53] It is also possible that myocardial fibrosis detected by CMR[54–56] will predict events in AS and aortic regurgitation, but further work is required before CMR can be used to recommend surgery in clinical routine. However CMR is far more accurate than TTE for quantifying LV mass and is therefore useful in research studies to document the regression of LV hypertrophy after surgery.[57]

CMR is already used routinely for the assessment of the right ventricle (RV) in adult congenital heart disease and it is also indicated in severe tricuspid or pulmonary regurgitation where decisions for surgery rest on accurate assessment of RV volume, or a serial change in RV size or function.

CT can also accurately quantify global left and right ventricular function, as well as LV mass, but is not regarded as the first-choice modality for these parameters due to the higher radiation doses required and availability of other techniques. Where CT is also required for other indications however (e.g. CT coronary angiography), or in patients with pacemakers, LV and RV functional assessment may be usefully performed.

Aorta

TTE is excellent at imaging the aortic root and can usually detect aortic coarctation. However, views of the distal ascending and the descending aorta are often suboptimal. Although transoesophageal echocardiography (TEE) is sensitive for the ascending aorta and upper descending thoracic aorta, it is semi-invasive and not suited for serial studies. For this reason, CT or CMR[58] should be performed at baseline if there is a high risk of aortic dilatation and the aorta above the root has not been adequately imaged by echocardiography, for example in the case of bicuspid valve or Marfan syndrome. Where CT/CMR has confirmed that echocardiographic measures of the proximal aorta are accurate, echocardiography should be the technique for serial measurement, but if the distal aorta beyond the reach of echocardiography is dilated, serial CT or CMR should be conducted. Even if the ascending aorta is adequately imaged on echocardiography, it is reasonable to repeat a CT or CMR study when the size of the aorta approaches surgical thresholds.

Risk assessment

TTE predicts a high risk of events in AS if the maximum transvalvar velocity by Doppler (Vmax) is >5.0 m/s,[59,60] or if the Vmax increases by >0.3 m/s in 1 year with associated heavy calcification assessed subjectively.[61] Quantification of calcification by CT is more accurate[51] and likely to be incorporated in clinical algorithms although there is no consensus on cutpoints yet.

Quantification of mitral regurgitation by TTE or TEE correlates well with outcome,[62] 'Watchful waiting' with current echocardiographic and clinical thresholds for surgery have a similar outcome to immediate surgery for repairable degenerative disease.[63] However, early work suggests that CMR measures of regurgitant volume/fraction may better predict the need for future surgery.[53] TTE measures of aortic regurgitation correlate less well with outcome and CMR shows promise as a better marker of risk.[52]

Severe LV hypertrophy on TTE suggests a high risk of events[64] but this is difficult to quantify. CMR may be better for risk assessment by showing patchy mid-wall fibrosis as a sign of early LV strain in AS.

Exercise stress echocardiography shows a high risk of events in asymptomatic AS by the failure of contractile reserve[65] or a rise in mean gradient >20 mmHg with a baseline mean gradient >35 mmHg.[66–68] There are relatively few studies and this indication is not in routine clinical use but could be considered in individual cases, e.g. borderline indications for surgery on the resting study or before non-cardiac surgery or planned pregnancy.[69,70]

Table 2 Guide to frequency of routine serial echocardiography for valve disease

Aortic valve disease	
Aortic valve thickening with no stenosis and trace or mild AR	No follow-up usually needed
Bicuspid with no AS and no more than mild AR	3–5 years
Bicuspid with valve thickening and mild AS	2 years
Tricuspid AV with mild AS with little calcification	3–5 years
Moderate AS	1–2 years
AS with Vmax>3.5 m/s and with heavy calcification or severe AS	6–12 months
Mild to moderate AR	3–5 years
Moderate AR	1–2 years
Severe AR	6–12 months
Mitral valve disease	
Normal MV appearance and trace to mild MR	No follow-up usually needed
Mild prolapse and mild MR	5 years
Moderate MR	2 years
Severe MR close to cutpoints for surgery or no previous study	6 months or less
Severe MR and normal LV	6–12 months
Right-sided	
PS mild (Vmax < 3 m/s)	5 years
Moderate	2 years
Severe PS	1 year
Mild or moderate TR and normal valve and RV	No follow-up usually needed
Severe TR	1 year
Aorta (echo, CT, or CMR)	
Non-dilated with Turner's syndrome	5 years
Dilatation unless high risk or close to cutpoints for surgery	1 year

AR, aortic regurgitation; AS, aortic stenosis; CMR, cardiac magnetic resonance; CT, computed tomography; LV, left ventricle; RV, right ventricle; PS, pulmonary stenosis; Vmax, peak transaortic velocity.

Surveillance

The frequency of TTE surveillance for native VHD can be based on the suggestions in *Table 2*. However individualized decisions will need to be made for example based on proximity to cutpoints for surgery, previous high rate of progression, equivocal signs of LV dilatation or decompensation or uncertainty about symptoms. There is also growing evidence that the presence of significant calcification interacts with conventional assessment of severity based on Doppler.[61,71] Patients with moderate AS and a Vmax >3.5 m/s in the presence of heavy calcification should probably be followed more frequently than those with Vmax <3.5 m/s and little calcification.[71]

Most specialist valve clinic follows patients with moderate or severe disease to determine the optimum time for surgery.[13,14] There is good consensus about the frequency of follow-up for these cases. There is less certainty about patients with mild disease who are increasingly likely to be detected as the use of echocardiography widens. Few studies of the natural history of mild disease exist and inferences about progression must usually be drawn from age-related prevalences in cross-sectional studies. Mild AS (Vmax 2.5–3.0 m/s) has a risk of events including aortic valve replacement surgery of 30–38% at 5 years[71,72] although the risk is lower in the absence of significant calcification assessed by eye.[71] However, aortic sclerosis with insignificant restriction of opening progresses slowly with 2.5% reaching severe stenosis at 8 years[73] and does not require regular surveillance if detected in people aged >65. Trace to mild aortic regurgitation associated with a normal root and ascending aorta and trace to mild mitral regurgitation with a normal mitral valve appearance progress slowly[74,75] and do not usually require surveillance echocardiography. Mild rheumatic aortic regurgitation present at the time of surgery for mitral disease also progresses slowly[76] and requires surveillance every 5 years. Those with a normally functioning bicuspid aortic valve require surveillance every 3–5 years.[77,78] Mitral prolapse occurs in approximately 2–5% of the population.[79–81] There is a low risk of progression if the prolapse is mild with no more than mild mitral regurgitation and a normal left atrial size in sinus rhythm and for these follow-ups may not be required[82] and at most every 5 years.[60]

Local arrangements must also determine whether a patient who is not a surgical candidate is better followed in a specialist valve clinic or in a heart failure or elderly care clinic. In this situation, surveillance echocardiography may no longer be indicated.

In pregnancy the WHO recommends TTE surveillance[83] in risk category I (no more than mild valve disease with good LV function) once or twice during the pregnancy, and in risk category II (moderate AS, severe aortic or mitral regurgitation, biological replacement valve) every trimester. For risk category III (severe asymptomatic AS, moderate mitral stenosis, mechanical replacement valves) and

Table 3 Frequencies for surveillance TTE for replacement valves following a normal baseline post-operative study

Mechanical valve	No routine follow-up usually needed[a]
Biological valve	Annual from implantation: TAVI, new designs for which durability data do not exist, Ross procedure
	Annual ≥5 years: mitral or tricuspid position,[b] aortic xenograft age <50 at implantation (or other major risk factors, e.g. renal failure, severe patient–prosthesis mismatch)
	Annual ≥10 years: aortic xenografts age ≥50 at implantation
Valve repair	Annual: for functional mitral regurgitation or repair of rheumatic disease or complex degenerative disease or aortic valve
	For degenerative mitral repair, echo at 1 year, then discharge if good function. If residual regurgitation follow as for native mitral regurgitation

[a]Unless other indications exist, e.g. LV dysfunction, dilated aorta, or residual tricuspid regurgitation.
[b]Consider annually from implantation with high risk for structural valve deterioration, e.g. age <50 at implantation, renal dysfunction, systemic hypertension, diabetes.

category IV, echocardiography is recommended every 1–2 months.[69,70] The rationale for frequent echocardiography in severe AS is to detect early LV systolic dysfunction and progressive pulmonary hypertension as possible reasons for premature ending of the pregnancy or early intervention for the AS. In the presence of a normally functioning mechanical valve and no symptoms, it is not clear that TTE more frequently than once each trimester is indicated. The risk of valve thrombosis using low molecular weight heparin in the first trimester followed by a vitamin K antagonist is approximately 10% compared with about 3% using warfarin throughout.[84,85] It may be appropriate to individualize the frequency of TTE based on the success of monitoring with International Normalised Ratio (INR) or anti-Xa levels and the valve position. The risk of thrombosis is higher for the mitral than the aortic position.

Surveillance of a dilated aorta is performed by TTE or by CT or CMR if the aorta is dilated at baseline at a level out of the echocardiography window. The choice between CT and CMR depends on individual and local factors including the presence of claustrophobia or the radiation dosage from the CT scanner in use. Once chosen the same cross-sectional technique should be used for serial studies. In the presence of conditions at relatively high-risk of dissection (e.g. Marfan or Lowys–Dietz syndromes), a repeat scan is recommended 6 months after baseline[84] and thereafter every 1 year.[60] In Turner's syndrome with a normal aorta at baseline, follow-up should be performed every 5 years.[26,86]

CMR surveillance is routine for RV size in severe pulmonary regurgitation and it is reasonable to consider this also for tricuspid regurgitation.

Intervention

Pre-operatively

TTE should be performed before valve surgery to confirm the VHD and LV and RV adaptations if a previous study has not been carried out within 3 months or if there has been a clinically significant change. The study should be reviewed to refine the surgery planned, for example the addition of MV (mitral valve) surgery in a patient with dominant aortic stenosis (AS). TTE and TEE are the main methods for assessing the mitral valve prior to balloon valvotomy. For mitral valve repair procedures, TEE may be needed if 2D and 3D TTE do not allow a complete description of valve morphology.

The aorta is often not well imaged by TTE. CT should then be performed and should be considered routinely when considering aortic valve surgery to assess calcification of the ascending aorta and identify porcelain aorta as an indication for a transcatheter procedure instead of conventional surgery.[3,87] CT can also provide assessment of the coronary arteries in a single examination and can also show the course and proximity of venous and arterial bypass grafts to the sternum if redo sternotomy is planned. CT can provide an assessment of mitral annular calcification if this appears severe on TTE to help determine the feasibility and safety of mitral repair or replacement. CT is also useful in the work up for transcatheter valve implantation (TAVI), providing information additional to echocardiography including the degree of calcification of the leaflets, the distance to the coronary arteries and the calibre, tortuosity and calcific burden of the peripheral vessels.[88] For percutaneous mitral valve interventions, CT may also be useful in further defining mitral valve anatomy and the subvalvular structures including false tendons and hypertrabeculation.

CMR can also accurately assess the anatomy and size of the aorta prior to cardiac surgery and can be a good alternative to CT, but does not show the degree of calcification well, and does not have the resolution to robustly assess coronary artery patency. Where coronary disease is present however, it can provide excellent assessment of myocardial viability.

Perioperatively

Intraoperative TEE is essential for all valve surgery.[39,60] In replacement valves, it confirms good function with no para-prosthetic regurgitation. It also ensures that coexisting valve disease is discovered and that complications do not arise or are identified immediately (e.g. perforation of anterior mitral valve leaflet during valvular or supravalvular aortic surgery). It is particularly important to confirm competency of mitral and aortic valve repairs[88–90] and the absence of systolic anterior motion of the anterior mitral valve leaflet.

TEE is also essential for the assessment of any potential complications arising on the Intensive Therapy Unit following surgery, although some (e.g. pericardial effusions) may be detected simply by TTE.

Post-operatively

TTE should be performed before discharge to check the integrity of the valve, the LV and RV, and the presence of a pericardial effusion.

Ideally it should be performed again at 4–6 weeks[91] for a definitive study of the haemodynamic 'blueprint' of the replacement valve when image quality is better, perioperative LV dysfunction has improved and any pericardial fluid fully resolved. The patient should be in a stable rhythm and ventricular rate.

Thereafter, echocardiography should be performed if there are symptoms or signs of dysfunction or the clinical suspicion of infective endocarditis. However echocardiography should not be part of a 'fever screen' because this risks overinterpretation of normal appearances (e.g. pivotal washing jets), normal variants (e.g. fibrin strands), or artefact (e.g. side-lobe effects). TTE and where indicated TEE are also necessary for associated pathology e.g. LV dysfunction, dilated aorta, aortic valve disease, significant residual tricuspid regurgitation.

Routine TTE for mechanical replacement valves found to be normally functioning at baseline is not necessary in the absence of associated pathology because structural degeneration of modern designs of mechanical valves almost never occurs. For biological replacement valves, the American Heart Association currently recommends routine annual follow-up beyond 10 years after replacement[60] whereas the European Society of Cardiology recommends routine annual echocardiography after 5 years[39] or earlier in young patients. In general, the failure rate at 10 years is 20% for xenograft valves in the aortic position and 40% for those in the mitral position.[92] However, the failure rate is dependent on a number of factors including valve design, age at implantation, patient–prosthesis mismatch, systemic hypertension, and diabetes.[93,94] For these reasons, the frequency of follow-up may need to be individualized according to the design of the valve, the age at implantation, and the position of the valve. For example, a biological mitral valve implanted in a patient aged below 50 years should be studied annually from 5 years after implantation. In contrast, a biological valve in the aortic position in a patient aged over 65 can be followed from 10 years. Durability data are best for the Edwards Perimount and Medtronic Hancock II.[95,96] Newer designs of valve with an uncertain failure rate should be considered for annual follow-up from 5 years after implantation. The Ross procedure and transcatheter valves should have annual echocardiography. Homografts can have surveillance as for xenografts (*Table 3*).

Surveillance of mitral valve repair should be based on the likelihood of failure. This may not be low for repair of rheumatic disease, complex degenerative disease or secondary mitral regurgitation.[97] In these cases annual follow-up is recommended. However, after successful mitral valve repair for single scallop prolapse, without extensive myxomatous degeneration of the leaflets routine follow-up is not necessary beyond the first year after surgery because the failure rate is very low.[98]

CT or CMR is not indicated routinely but CMR may image and quantify regurgitation if not clear on TTE, especially following TAVI where multiple jets may make assessment difficult. CT may be indicated to assess early post-surgical complications, as well as suspected prosthesis obstruction (thrombus) or endocarditis.

Conclusion

Transthoracic echocardiography remains the mainstay for imaging native and replacement VHD. 3D echocardiography is now routine when available for the assessment of cardiac volumes and the morphology of the mitral valve. Stress echocardiography is routine for low-flow low-gradient AS when the EF is reduced and in the presence of symptoms despite moderate AS. TEE is complementary to TTE and particularly useful if there is at least a moderate clinical possibility of infective endocarditis or for assessing replacement mitral valves. Its use to assess the aorta in chronic valve disease has diminished with the rise of CMR and CT. These techniques are also useful for assessing the valves when echocardiographic images are suboptimal but increasingly are able to offer complementary information particularly to aid risk assessment. A true multimodality approach to imaging valve disease is now possible. This means using each technique according to its strengths to piece together different parts of a full clinical assessment which would not be possible with each alone. Current examples are:

- Bicuspid aortic valve disease assessed by echocardiography and the aorta by CMR or CT;
- Possible low-flow, low-gradient severe AS identified on echocardiography complemented by aortic valve calcium scoring using CT;
- Pulmonary regurgitation identified on echocardiography and RV volumes assessed by CMR;
- Assessment before transcatheter aortic or mitral valve procedures using echo and CT.

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