EACVI appropriateness criteria for the use of transthoracic echocardiography in adults: a report of literature and current practice review

Richard P. Steeds[1]*, Madalina Garbi[2], Nuno Cardim[3], Jaroslaw D. Kasprzak[4], Elif Sade[5], Petros Nihoyannopoulos[6], Bogdan Alexandru Popescu[7], Alexandros Stefanidis[8], Bernard Cosyns[9], Mark Monaghan[10], Svend Aakhus[11], Thor Edvardsen[12], Frank Flachskampf[13], Leonarda Galiuto[14], George Athanassopoulos[15], and Patrizio Lancellotti[16]

This document was reviewed by members of the 20142016 EACVI Scientific Documents Committee: Dr Victoria Delgado, Prof Erwan Donal, Dr Maurizio Galderisi, Dr Massimo Lombardi, Dr Denisa Muraru, Assoc Prof Kristina Haugaa.

[1]University Hospital Birmingham NHS Foundation Trust, Mindelsohn Road, Edgbaston, Birmingham, UK B15 2GW and Honorary Reader, Institute of Cardiovascular Sciences, University of Birmingham; UK; [2]King's College Hospital NHS Foundation Trust, Denmark Hill, London, SE5 9RS UK; [3]Echocardiography Laboratory, Hospital da Luz Av. LusÚada, n° 100 - 1500-650, Lisbon, Portugal; [4]Department of Cardiology, Bieganski Hospital Medical University of Lodz, Kniaziewicza 1/5, 91-347, Lodz, Poland; [5]Department of Cardiology, Baskent University School of Medicine, Fevzi úakmak Cad. 10. Sok. Bahcelievler 06490 Ankara, Turkey; [6]Imperial College London, NHLI Hammersmith Hospital, Du Cane Road, London W12 0NN, UK and University of Athens, Greece; [7]University of Medicine and Pharmacy "Carol Davila"—Euroecolab, Institute of Cardiovascular Diseases, Sos. Fundeni 258, sector 2, 022328, Bucharest, Romania; [8]1st Department of Cardiology, General Hospital of Nikea, 3 P. Mela str., 184 54, Athens, Greece; [9]Department of Cardiology, CHVZ (Centrum voor Hart en Vaatziekten)Universitair Ziekenhuis, VUB, Laarbeeklaan 101, 1090 Jette, Brussel, Belgium; [10]King's College Hospital NHS Foundation Trust, Denmark Hill, London, SE5 9RS UK; [11]Department of Cardiology, Oslo University Hospital, postboks 4950 Nydalen, 0424 Oslo and Faculty of Medicine, Norwegian University of Science and Technology, NTNU, 7491 Trondheim; [12]Department of Cardiology, Oslo University Hospital, Rikshospitalet, Sognsvannsveien 20, NO-0027 Oslo , Norway; [13]Department of Medical Sciences, Clinical Physiology, Uppsala University, Akademiska ingang 40, 751 85 Uppsala, Sweden; [14]Department of Cardiovascular Sciences, Catholic University of the Sacred Heart, Policlinico Agostino Gemelli, Largo A Gemelli 8, 00168 Roma, Italy; [15]Cardiology Section, Onassis Cardiac Surgery Center, Sygrou, 17674, Athens, Greece; and [16]Departments of Cardiology, University of Lie'ge Hospital, GIGA Cardiovascular Sciences, Heart Valve Clinic, CHU Sart Tilman, Lie'ge, Belgium and Gruppo Villa Maria Care and Research, Anthea, Hospital, Bari, Italy

The European Association for Cardiovascular Imaging (EACVI) has outlined the rationale for setting appropriate use criteria (AUC) in cardiovascular (CV) imaging. Transthoracic echocardiography (TTE) is the most common imaging modality in CV disease and is a central tool in diagnosis, follow-up, management planning and intervention. The purpose of AUC is to inform referrers, both to avoid under-use, which may result in incomplete or incorrect diagnosis and treatment, and also over-use, which may delay correct diagnosis, lead to 'treatment cascade', and wastes resources. The first step in defining AUC for TTE in the adult has been for a panel of experts in echocardiography to review the evidence, guidelines, recommendations, and position papers from the European Society of Cardiology, EACVI and other specialist societies, and current state-of-the-art clinical practice. The attached document summarizes this work, which will be used to under-pin the development of AUC.

Introduction

Transthoracic echocardiography (TTE) is a central tool in the diagnosis and management of cardiovascular (CV) disease that has contributed to a halving in the frequency of major diagnostic errors over the last 20 years.[1] Although use of TTE appears to grow inexorably and excessive use is discouraged given the increasing costs of health-care, there is evidence that it continues to be under-utilized in critical CV conditions.[2] This literature review aims to inform the development of European Appropriate Use Criteria (AUC) for TTE in the adult.

Table I   Clinical scenarios for echocardiography in the emergency setting

Scenario	Conditions identified on TTE	Focus of assessment
Cardiac arrest	Tamponade, massive pulmonary embolism, tension pneumothorax, hypovolaemia, complications of acute MI and severe systolic dysfunction.	LV size and function, RV size and function, proximal aorta, pericardium
Shortness of breath	Acute heart failure with or without preserved EF (HF), valvular heart disease (VHD), pulmonary arterial disease, coronary artery disease (CAD), cardiomyopathy (CM) and pericardial disease	LV size, wall thickness and function, RV size and function, pericardium
Chest pain	Acute coronary syndrome, acute aortic syndromes, pulmonary embolism, and pericardial disease	LV size and function, RV size and function, aorta, pericardium
Cardiac trauma	Direct effects of trauma and complications, transient regional wall motion abnormalities and ventricular dilatation, cardiac rupture, valve lesions, aortic dehiscence, pericardial effusion.	RV size and function, right heart valves, proximal aorta, pericardium
Syncope and palpitations	Structural heart disease leading to haemodynamic instability and arrhythmia, including acquired and congenital heart disease	LV size, wall thickness and function, RV size and function, valves
Cardiac emergency identified by other investigation	Biomarker elevation and major adverse radiological finding	LV size, wall thickness and function, RV size and function, pericardium, aorta

Echocardiography in the emergency setting

This section relates to the use of TTE in serious, unexpected situations that are potentially life threatening and may require immediate action (*Table 1*).

Cardiac arrest

A number of causes of cardiac arrest may be identified promptly on echocardiography without interference with the quality of resuscitation, including tamponade, massive pulmonary embolism, tension pneumothorax, hypovolaemia, complications of acute MI, and severe systolic dysfunction.[3] The use of TTE in these situations provides additional information to clinical examination by measurement of ventricular size and function, including wall motion, pericardial effusion, estimation of intracardiac and intrapulmonary pressure and wall motion without compromise to the patient. Immediate echocardiography is mandatory in patients with haemodynamic instability, particularly in those patients suspected of having acute, life-threatening structural or functional cardiovascular abnormalities such as acute valvar regurgitation, pericardial tamponade, and aortic dissection.

Shortness of breath (SOB)

Severe, persistent, abrupt onset or rapidly progressive SOB due to a range of causes is a common reason for emergency presentation. TTE is the imaging modality of choice and provides incremental diagnostic information with respect to the most common CV causes, most frequently acute heart failure with or without preserved EF (HF), valvular heart disease (VHD), pulmonary arterial disease, coronary artery disease (CAD), cardiomyopathy (CM), and pericardial disease.[4] In addition, TTE adds incremental information to clinical and radiological examination in patients with chronic lung disease who have suffered an unexplained, sudden change in clinical status. In these patients, early TTE may help to separate patients with cardiogenic shock, in which case urgent pharmacological or mechanical circulatory support should be instituted, from those with respiratory failure, in which case urgent non-invasive positive pressure ventilation or mechanical ventilatory support may be required. Early TTE enables prompt recognition of left vs. right-sided pressure and volume overload, thereby directing both diagnosis and management.

Acute heart failure

HF is the most frequent CV cause of hospitalization with SOB. In all patients with acute onset of symptoms and suspected HF, early TTE is mandated.[5] TTE provides immediate information on chamber volumes, ventricular systolic and diastolic function, filling pressure, wall thickness, valve function and presence of pericardial effusion (PEff), while contributing to information on aetiology. Although TTE is frequently used in these situations, no large-scale randomized studies comparing different diagnostic strategies with and without TTE exist.

There is growing evidence to support the use of pocket size echo devices (PSED) to supplement physical examination and provide more rapid, accurate clinical diagnosis in emergency situations.[6] A further alternative, although a comprehensive TTE provides more information, may be to perform focused TTE in critically-ill patients in whom predominantly rapid, qualitative, gross assessment of cardiac morphology, and function may be sufficient to guide treatment.[7] Lung ultrasound may be performed with both PSED and standard echocardiography equipment and is helpful in distinguishing the cause of acute breathlessness, including pneumothorax, interstitial oedema, and pleural effusions.[8]

Pulmonary embolism (PE)

TTE may rarely identify main and proximal PE, although this finding is associated with increased mortality.[9] Numerous echocardiographic

criteria for the diagnosis of PE have been identified which mostly rely on secondary consequences of pressure overload on the right ventricle, in which situation TTE has higher specificity.[10] Although the negative predictive value for PE overall is only 40–50%, TTE has a role in promoting the diagnosis, for example with McConnell's sign, excluding differential diagnoses and in defining management. If clinical suspicion remains after TTE, further imaging using alternate modalities is required to confirm or refute the diagnosis of PE.[11] Routine TTE is not mandatory in the emergency setting in all cases but should be performed in the non-urgent setting with a view to assessment of complications.

While TTE has a limited role in diagnosis, in the emergency setting in normotensive patients, tricuspid annular plane systolic excursion below 15 mm carries adverse prognostic significance.[12] In normotensive patients with RV dysfunction on TTE, the benefits of rescue reperfusion therapy appear to be limited to the avoidance of haemodynamic compromise but at greater bleeding risk.[13] In acute PE with haemodynamic collapse, rescue reperfusion therapy may be indicated without TTE.

Acute pulmonary disease

TTE may be used to diagnose a large pleural effusion or pneumothorax, and to differentiate interstitial pulmonary oedema from pneumonia by the identification of linear artefacts called 'lung comets'.[14] The acoustic windows used and views required are not however standard, and additional training may be required for this use.

Acute valvular heart disease

A murmur in a patient with acute cardiorespiratory compromise is an indication for urgent TEE. Echocardiography detects abnormalities of valve morphology and function, aetiology including IE, and haemodynamic effects on chamber size and function. In emergency admissions, VHD is likely to be severe and to affect the left-sided valves, including flail MV and AV leaflets, prosthetic valve dehiscence, and valve perforation in infective endocarditis.[4]

Chest pain

Identifying the aetiology of acute chest pain is often challenging and requires careful history and examination, with the first step a 12-lead electrocardiogram (ECG) if acute coronary syndrome is suspected. When the history, ECG and biomarker findings are inconclusive, TTE is then the most important imaging modality in the emergency setting, not only because it can demonstrate transient wall motion abnormalities during ischaemia and tako-tsubo but also because it may highlight differential diagnoses including aortic dissection, PE, and pericardial disease.[15] TTE has a limited role in the diagnosis of acute myocarditis, although the identification of PEff due to acute pericarditis presenting with haemodynamic compromise is important.[16]

Acute coronary syndrome (ACS)

In those patients with a history and examination suggestive of ACS, current guidelines recommend immediate angiography following 12-lead ECG in those with ST-segment elevation MI.[17] In those cases when history, clinical risk score, and ECG fail to diagnose an ACS, both myocardial contrast for perfusion and strain TTE may improve diagnostic accuracy before serum biomarker results become available

dependent on local expertise.[18] While the sensitivity of 2D-TTE wall motion analysis for detecting an acute coronary occlusion in ACS is only 71% in the modern biomarker era, this is substantially improved with the addition of regional strain analysis to 90%.[19] LV opacification contrast should be used where image quality is sub-optimal and two or more myocardial segments cannot be adequately visualized. In addition, focused TTE should be available in the emergency room and chest pain unit as it can be helpful to detect alternative pathologies, such as proximal aortic dissection involving the coronary ostia, without delaying revascularization.

Acute aortic syndromes

This term refers to the spectrum of aortic pathologies, comprising aortic dissection, intramural haematoma, penetrating aortic ulcer, and aortic aneurysm rupture. Prompt and accurate diagnosis of these conditions is paramount due to their potentially lethal nature. Non-invasive imaging techniques that play a core role include computed tomography (CT), transesophageal echocardiography (TEE), magnetic resonance imaging (CMR) and TTE. The sensitivity of TTE has improved such that it can be considered as the first-line imaging modality in the emergency room but, if negative, further imaging should be performed.[20] For any test performed under these circumstances, expert interpretation is required to minimize risk of false positive and false negative results, which may be a particular problem in this clinical scenario.

Chest trauma

TTE should be used to assess the consequences of penetrating cardiac trauma, although blunt cardiac contusion is more common. The latter may cause a spectrum of pathology from transient regional wall motion abnormalities to cardiac rupture, valve lesions (frequently tricuspid), and aortic dehiscence. Echocardiography has high sensitivity for detection of the complications of contusion, including intracardiac shunts or thrombosis, PEff or tamponade, and ventricular dilatation.[21]

Syncope or palpitations

There is a broad overlap in the clinical presentations of patients with syncope in the emergency room that may potentially be due to ventricular and supraventricular arrhythmias, as well as to other non-arrhythmic causes such as hypovolaemia, pericardial tamponade, dynamic LV outflow tract obstruction in HCM and severe VHD. The management and prognosis of each patient depends both on their hemodynamic status on arrival and on severity of underlying CV disease. TTE is the first line imaging modality for diagnosis of underlying myocardial, valvular and congenital disorders in highly symptomatic patients with high-grade atrio-ventricular block, ventricular and supraventricular arrhythmia and in complicated new-onset atrial fibrillation. The aims of imaging are not only diagnosis but also prognosis, guidance of therapy and monitoring.[4] A normal TTE in this setting is an important finding that helps to direct the clinician in diagnosis and management. Presentation with palpitations may require the same diagnostic and prognostic assessment as for syncope, although urgency of imaging depends on haemodynamic compromise.

Cardiac emergency suspected following other investigation

This section refers to the use of TTE following another investigation that has highlighted a serious, unexpected, potentially life-threatening condition that may require immediate action. Most commonly the investigations include elevated cardiac biomarkers and abnormal radiological findings.

Elevated troponin

Cardiac troponin testing is essential in the assessment of acute chest pain. The role of TTE in those with suspected ACS has been discussed but particularly with high sensitivity assays, circulating troponin can be detected within 2–3 hrs in many other conditions, including heart failure, aortic valve disease, acute aortic syndromes, hypertrophic and restrictive cardiomyopathies, Tako-tsubo syndrome, endocarditis, and myocarditis. Dependent on clinical circumstances, early TTE may be important to direct treatment in these circumstances, particularly in patients with shock, when troponin may be elevated in critical illness due to non-cardiac causes including sepsis, acute renal failure and burns. In these cases, TTE has an important role not only in excluding a cardiac component to hemodynamic compromise but also in monitoring filling pressure, response to volume-loading and pharmacotherapy.[22]

Elevated natriuretic peptides

Natriuretic peptides as markers of myocardial stretch are typically elevated when heart chambers dilate as in HF, especially acutely, but also in acute cardiomyopathies, severe VHD and arrhythmias.[23] Natriuretic peptides may be elevated in non-primary cardiac illnesses, including critical sepsis, severe anemia, stroke and pulmonary disease, including PH.[24] TTE may provide important additional diagnostic and prognostic information in the critically ill patient.

Radiological abnormality

While a standard chest-X-ray is not an accurate method for diagnosis of cardiomegaly or thoracic aortic dilatation, such a finding in the emergency room in a patient with relevant symptoms, signs or past medical history mandates early TTE.

Assessment of the patient prior to non-cardiac emergency surgery

Prior to emergency non-cardiac surgery, the utility of TTE is unclear due to the need for urgent intervention. Although there is a lack of data, expert consensus suggests that TTE does not change the course and outcomes of an urgent intervention, such as those for ruptured abdominal aortic aneurysm, major trauma or perforated viscus, whether or not the patient has a history of CV disease.[25]

Echocardiography in the non-urgent, first assessment of the patient

This section relates to the first use of TTE in patients hospitalized (in-patient) or investigated as out-patients (*Table 2*). TTE will usually follow the same protocol in either setting and there may be no difference in the indication for examination in many cases. This section outlines evidence relating to the first use of TTE.

Shortness of breath

SOB is a common symptom affecting up to half of all acute hospital admissions and a quarter of ambulatory patients and it may be the primary manifestation of CV disease, lung disease, anaemia, obesity, deconditioning and a host of other causes. In any setting, clinical history and examination remain the first step in evaluation, although TTE may improve accuracy in diagnosis and provide incremental information.[26]

Acute and chronic heart failure

In all patients with suspected heart failure, early TTE is mandated. The aims of TTE are to confirm or exclude the diagnosis, quantify chamber volumes, systolic and LV diastolic function, wall thickness and to identify the aetiology of heart failure. TTE provides an initial diagnosis and treatment plan in the majority of patients; other imaging may only be required if the diagnosis remains unclear.[5] It is the primary imaging modality to identify HF with preserved, mid range or reduced EF in those with breathlessness. TTE is also mandated in patients with known HF presenting with acute exacerbation, for identification of a precipitating factor for deterioration.

Valvular heart disease (VHD)

SOB is the leading symptom of mitral valve disease, and is a common presentation for a patient with VHD of any type. In patients presenting with SOB and suspected VHD based on history and/or examination, TTE is the primary imaging modality for diagnosis, assessment of severity and of hemodynamic consequences.[27]

Cardiomyopathy (CM)

SOB may be a presenting symptom in CM of all types and TTE is a fundamental step in diagnosis and classification of type, specifically hypertrophic, dilated, arrhythmogenic, restrictive and unclassified cardiomyopathies.[28] It is also recognized that TTE should form the first step in differentiating the heart of the athlete from serious cardiovascular disease that may share morphological features.[29]

Hypertrophic cardiomyopathy (HCM)

TTE is the primary imaging modality in patients with HCM, providing information on diagnosis, anatomy (LV hypertrophy, mitral valve apparatus, intraventricular and LV outflow tract obstruction), ventricular systolic and diastolic function, mitral regurgitation, ischaemia, staging and risk stratification. Supplementary manoeuvres, including Valsalva and ergometric testing, may be necessary to identify significant LVOT obstruction. TTE is an important tool to separate HCM from phenocopies.[30]

Dilated cardiomyopathy (DCM)

DCM is defined by the presence of LV dilatation and LV systolic dysfunction in the absence of abnormal loading conditions (hypertension, valve disease) or coronary artery disease sufficient to cause global systolic impairment. TTE is the primary imaging modality in

Table 2 Clinical scenarios for echocardiography in the non-urgent, first assessment of the patient

Scenario	Conditions identified on TTE	Focus of assessment
Shortness of breath	Acute and chronic HF, VHD, cardiomyopathy, pericardial disease, pulmonary vascular disease, pulmonary hypertension	LV size, wall thickness and function, RV size and function, valve function, pericardium
Chest pain	Acute coronary syndrome, chronic stable angina, VHD, acute aortic syndromes, pulmonary embolism, and pericardial disease	LV size and function, RV size and function, valve function, aorta, pericardium
Syncope, palpitations, arrhythmia	Structural heart disease leading to haemodynamic instability and arrhythmia, including acquired and congenital heart disease	LV size, wall thickness and function, RV size and function, valve function, arterial and venous connections
Cardiac disease identified by other investigation	Acute and chronic HF, acute coronary syndromes, VHD, cardiomyopathy, pericardial effusion	LV size and function, RV size and function, valve function
Infective endocarditis	Supporting evidence of IE and/or complications thereof	High resolution valve assessment and complications
Emboli and cardiac masses	Mass consistent with thrombus, tumour, vegetations	Characterization of mass, size, location and involvement of adjacent structures
Patients at risk of CV disease	Hypertension, genetic predisposition to cardiac disease, exposure to cardiotoxic medications	LV size, wall thickness and function, including advanced characterization of diastolic function and deformation, RV size and function
Adult congenital heart disease	Broad range of inherited conditions with de novo presentation or previous surgery	Segmental analysis to define arterial and venous connections, valve and ventricular morphology and function, intracardiac pressure and shunts
Prior to planned non-cardiac surgery	Active cardiovascular symptoms or proven CV disease	LV size, wall thickness and function, RV size and function, valve function

DCM, providing information on diagnosis, severity of ventricular dysfunction, staging and risk stratification.

Arrhythmogenic right ventricular cardiomyopathy (ARVC)
ARVC is characterized histologically by progressive replacement of RV myocardium with adipose and fibrous tissue, frequently leading to functional and morphological abnormalities that may be diagnosed on TTE.[31] Detection of RV dilatation and RV dysfunction in association with regional hypokinesis represent major and minor diagnostic imaging criteria, while it is also important to ensure there is a low likelihood of pulmonary hypertension. TTE is the primary imaging modality, although ARVC may be present in the absence of imaging criteria of any type.

Restrictive cardiomyopathies (RCM)
RCMs are defined by the presence of restrictive ventricular physiology with normal or reduced diastolic volumes (of one or both ventricles), normal or reduced systolic volumes, and normal ventricular wall thickness.[28] These may be familial, including haemochromatosis, Anderson-Fabry disease and glycogen storage disease, or non-familial, including AL and wild-type TTR amyloid, endomyocardial fibrosis and carcinoid heart disease. TTE is not only the main diagnostic imaging modality for RCM but is also useful for risk stratification.[32]

Lung disease
Two categories of patients with SOB and lung disease have been defined: (a) those presenting for the first time; (b) those presenting with an established diagnosis that may cause SOB but which has

deteriorated for no apparent reason.[33] The role of TTE in patients with primary lung disease presenting for the first time is not clear, except in those with suspected PE or PH. In those with established lung disease that may cause SOB but with unexplained deterioration, for example in chronic obstructive pulmonary disease and sleep apnoea syndrome, careful CV evaluation and TTE is necessary in order to detect complicating factors such as HF.[34]

Pulmonary vascular disease
CT, ventilation-perfusion imaging and pulmonary angiography are the imaging modalities of choice in the diagnosis of the non-urgent patient with suspected PE. TTE has a role during hospitalization as it identifies those at risk of acute deterioration and determines prognosis.[35] Furthermore, persistence of RV dysfunction on TTE at hospital discharge is a marker for recurrence of PE.[36]

Pulmonary hypertension (PH)
The diagnosis of PH requires a high index of suspicion, as symptoms and clinical signs are frequently non-specific and often relate to onset of RV dysfunction. Doppler echocardiography is used to estimate the pulmonary pressure from the maximal velocity of the tricuspid regurgitant jet (TR Vmax >2.8 m/sec), combined with additional variables including relative RV to LV size, RV/LV eccentricity index, RA area->18 cm^2, RV outflow tract acceleration time (<105 ms), pulmonary regurgitant velocity (>2.2 m/s), inferior vena cava dimensions and the pulmonary artery diameter >25 mm.[37] Assessment of RV size and function by TTE can be complicated by the need to use multiple acoustic windows and is less accurate than CMR in this respect. In

those with confirmed or suspected PH, TTE may help to determine a cause, in particular confirming or excluding the presence of left heart disease and Doppler can distinguish pre- and post-capillary pulmonary hypertension.

Chest pain

Ambulatory patients presenting with chest pain are common, although only a small proportion will have an ACS. In the community, the most common causes include chest wall pain (e.g. costochondritis), and gastro-oesophageal reflux disease, with other considerations including pulmonary aetiologies (pneumonia, pulmonary embolism) and psychological disorders (anxiety, panic disorder). The first step is to exclude ACS, usually based on clinical parameters, initial ECG and biomarker measurement.

Acute coronary syndrome

In patients with non-ST segment elevation ACS, management depends on information additional to history and clinical examination which comprises: the response to anti-ischaemic treatment, biomarker measurement (high sensitivity troponin), repeat ECG or continuous ST-segment monitoring, ischaemic risk score assessment (GRACE score) and TTE.[38] TTE is useful not only as a diagnostic tool but is important in risk stratification. The presence of LV systolic dysfunction has an independent prognostic role in predicting both short- and long-term cardiac events.[39,40]

Chronic stable angina

Although overall LV function is often normal in patients with stable angina, regional wall motion abnormalities may be identified that provide evidence in support of a diagnosis of CAD. In those with a confirmed diagnosis of chronic stable angina, TTE is useful to quantify global LV function, which is an important prognostic parameter.[41] In addition to 2D, tissue Doppler and myocardial deformation imaging, along with assessment of diastolic function are useful for detecting early myocardial dysfunction in those with preserved LV ejection fraction as an explanation for exercise-induced symptoms.[42]

Acute pericarditis

Acute pericarditis is an inflammatory syndrome with or without PEff. TTE is recommended in all patients in whom the diagnosis is suspected.[16] The aim of TTE is to identify PEff and to exclude ventricular dysfunction due to myocardial involvement. The presence of a large PEff (>20 mm) is one of the major risk factors for poor prognosis.[43]

Valvular heart disease

The development of chest pain during exercise in a patient with severe aortic stenosis in the absence of CAD is a clear indication for intervention and TTE is mandated in any patient presenting in this way who has a murmur or clinical evaluation consistent with this diagnosis.[27]

Acute aortic syndromes

Although TTE may be used in the emergency room, particularly in the assessment of the proximal ascending aorta, CT is the recommended first line imaging modality for those with suspected aortic syndromes in the non-emergent setting.[20] In the stable patient, TTE may complement CT by adding information on presence, severity and mechanism of aortic regurgitation, PEff, and LV function.

Syncope, palpitations, and arrythmia

Syncope and palpitations are among the most common symptoms leading to medical presentation and the role of TTE is to rule out structural cardiac disease where there is a clinical suspicion on examination or following a 12-lead ECG.[44,45] A normal TTE in this setting is an important finding that helps to direct the clinician in diagnosis and management. It is uncommon for TTE to define a sole cause for syncope or presyncope without the need for additional tests in the absence of a clinical suspicion of structural abnormality, since the most commonly identified causes such as aortic stenosis, HCM, DCM, ARVC, and pulmonary hypertension are usually at an advanced stage. In the presence of impaired LV function, other tests to evaluate a cardiac cause for syncope should be performed.[44] Diagnosis of the cause of palpitations is provided by electrocardiographic recording of a rhythm disorder or the absence of it at the time of symptoms and TTE is not indicated unless there is a clinical suspicion of structural heart disease on examination or following a 12-lead ECG. Likewise, in those patients with confirmed multiple premature ventricular complexes and/or sustained or non-sustained arrhythmias, including atrial fibrillation, supraventricular tachycardia and ventricular tachycardia, TTE is required for diagnosis of underlying structural CV disease, for risk stratification and planning treatment.[46,47]

Cardiac disease suspected following other investigation

Elevated troponin

Although cardiac troponin testing is integral to the diagnosis of chest pain in the acute medical patient, elevation is not synonymous with ACS. The value of TTE in patients with elevated troponin and suspected ACS has been discussed but the role of TTE in the patient with an alternative cause is more complex. All cardiac troponin elevations are important and may have prognostic significance. Firstly, in patients with an acute elevation in troponin but no evidence of ischaemia, for example in severe sepsis, stroke, or other critical illness, a dynamic change in biomarker is associated with high risk and TTE is useful for measurement of LV function.[48] Secondly, in patients with a chronic elevation in troponin, for example HF and kidney disease, while this is associated with adverse prognosis, the role of TTE in management is not clear. Thirdly, measurement of troponin may be used as a sensitive and specific marker of myocardial injury, for example in patients receiving cancer therapy. In these patients, elevation in biomarkers may be used to monitor the effects of chemotherapy, with elevation then a stimulus to TTE.[49] While change in ejection fraction is the most common method of diagnosis of cancer therapy-related cardiac dysfunction, global longitudinal strain is the optimal parameter of deformation for monitoring of sub-clinical LV dysfunction.[50]

Elevated natriuretic peptides

Since HF symptoms are non-specific, use of natriuretic peptides is recommended for screening patients with acute onset, worsening or gradual onset of symptoms.[51] TTE is then required to confirm or refute the diagnosis, and then to assess aetiology if a cardiac cause is

identified, since natriuretic peptides may be elevated in non-primary cardiac illnesses, including sepsis, severe anemia, stroke and pulmonary disease.[24]

Radiological abnormality

Increased cardiothoracic ratio on a standard chest-X-ray is a common finding often disproved on TTE.[52] Other findings on a CXR that prompt referral to TTE include a large thoracic aorta, pleural effusion or pulmonary congestion, while identification of a PEff on non-gated computed tomography may necessitate assessment to exclude impending tamponade.

Infective endocarditis (IE)

The diverse nature of IE and evolving epidemiology ensures that this condition remains a challenge. In addition to microbiological investigation, TTE is the technique of choice for diagnosis in those with fever of unknown origin and should be performed as soon as IE is suspected. In those with a confirmed diagnosis, TTE also plays a central role in planning management and monitoring outcome. TTE is recommended as first-line, with TEE indicated in those with a negative TTE but high clinical suspicion and as first-line in those with a prosthetic valve or intracardiac device. TEE is also considered useful following positive TTE.[53] Echocardiography of all patients with Staphylococcus aureus bacteraemia is recommended due to the high but unexpected prevalence of IE.[54]

Emboli

TTE is the first-line imaging modality of choice in those with potential cardiac source of embolism.[55] In these patients, there is likely to be an incremental advantage over and above the use of standard TTE with the addition of 3D, contrast and TEE. The type of echocardiography used depends on the clinical presentation. In patients with atrial arrhythmia, structures away from the chest wall, in particular the posterior aspect of the left atrium, left atrial appendage and descending thoracic aorta, are best imaged using TEE due to improved resolution. In patients with a recent history of ACS, particularly those with anterior MI, large infarct size, severe apical wall motion abnormality or LV aneurysm, TTE is the preferred technique but with the additional option of transpulmonary contrast to improve sensitivity in cases with suboptimal image quality.[56] In patients with cryptogenic stroke, TTE with agitated saline contrast and provocative manoeuvres including Valsalva is useful to detect patent foramen ovale and small ASDs, although controversy remains as to the role of closure and in which patients this imaging should be performed.[57,58]

Cardiac masses

TTE is the primary imaging modality for assessment of intracardiac masses, determining size, location and involvement of adjacent structures, as well as contrast techniques to distinguish thrombus from tumour.[59]

Echocardiography in the non-emergent, first assessment of the patient at risk of cardiac disease

Hypertension

The aims of TTE include the diagnosis of LV hypertrophy, assessment of LV geometry and measurement of diastolic function, including left atrial size.[60] Although TTE is more sensitive than ECG in diagnosing LVH and abnormalities detected by echocardiography have additional predictive power, there are no convincing data that TTE improves CV risk classification.[61] Evidence of LVH is one of the indicators of asymptomatic end-organ damage used to calculate total CV risk and may be used to direct therapy, as can carotid-intima medial thickness.

Diabetes mellitus

Successful risk management of DM depends upon accurate detection and intensive management of identifiable, modifiable risk factors, and clinical risk scores are the main method to identify those at low, medium and high risk. Although coronary artery disease and heart failure however, are common, screening with TTE is not recommended in asymptomatic patients with DM unless the ECG is abnormal.[62]

Dyslipidaemias

Although intervention for dyslipidaemias is directed by estimation of total CV risk, including presence or absence of hypertension, TTE does not play a role in risk profiling or targeting treatment in these patients.[63]

Asymptomatic adults

Routine screening with echocardiography and other imaging modalities is not recommended to predict CV events There is no evidence that screening for CV disease in asymptomatic adults with TTE–using stress or not–adds incremental value to the use of clinical risk algorithms.[64] Screening of asymptomatic adults >65 years for abdominal aortic aneurysms may be the exception and is recommended due to the grim prognosis of rupture compared to the excellent results of repair.[65]

Genetic predisposition and screening

The diagnosis of CV disease in asymptomatic patients and their relatives with known or suspected genetic predisposition to CV disease, for example Marfan syndrome, bicuspid AV, HCM, ARVC, relies upon a combination of history, clinical examination, genetic testing and imaging. While there are advantages and disadvantages to each imaging modality in specific cases and aetiologies, TTE is recommended in the initial evaluation of such patients and their family members due to the ability to define ventricular morphology and function, valvular abnormalities, and associated proximal aortopathy.[66]

Cardiotoxic therapy

Chemotherapy and radiotherapy are known to have multiple potential adverse effects on CV structure and function, although the timing of these effects vary dependent upon susceptibility of the patient and the treatment regime used. TTE is the cornerstone in the cardiac imaging evaluation of patients in preparation for, during, and after cancer therapy, because of its wide availability, easy repeatability,

versatility, lack of radiation exposure, and safety in patients with concomitant renal disease.[49] Recommended protocols using TTE encompass not only 2D assessment of structure and function but recommend the routine use of 3D and also deformation analysis for reproducible quantification of volumes and function, as well as standard assessment of strain, diastolic function, valvular abnormalities, and pericardial consequences of chemotherapy and radiotherapy.[50]

Adult congenital heart disease (ACHD)

ACHD encompasses a broad range of patients, from de novo presentations in adulthood to the assessment of patient with previous palliative repair and its consequences. Survival to adulthood is increasing, although varies with severity of disease, from 98% of those with mild disease to 56% of those with severe forms of ACHD.[67] With increasing life expectancy, there is the additional interaction between acquired disease and the consequences of ACHD, either precipitating symptoms in hitherto stable disease or onset of consequences from undiagnosed disease. TTE represents the first-line investigation for diagnosis and follow-up of ACHD, since a segmental approach will help to define arterial and venous connections, valve and ventricular morphology and function, and estimate intracardiac pressure and shunts.[68] While TTE is first-line, it is recognized that it is user dependent and requires special expertise in ACHD populations.

Assessment of the patient prior to planned non-cardiac surgery

The risk of CV complications during non-cardiac surgery depends upon the condition of the patient before surgery, the severity of his or her co-existing morbidity, and the magnitude, type and duration of surgery proposed. Alongside the risk attributable to specific types of surgery, the functional capacity of the patient is the most important patient-related factor to determine likelihood of peri-operative cardiac events.[25] Although TTE can identify patients at higher risk, its use should be reserved for those patients in whom the result would influence or change management and routine use is not recommended. For example, TTE is not recommended in those patients with stable heart disease undergoing low and intermediate-risk surgery but in symptomatic, unstable patients undergoing high risk surgery, careful evaluation of the patient by a team of integrated multidisciplinary specialists may be informed by TTE.

Repeat echocardiography following first study

This section relates to the second or repeated use of TTE in an in-patient or out-patient setting (*Table 3*). The echocardiographic examination will in most cases be a complete study acquiring a comprehensive set of images and measurements.[69] In the majority of cases, TTE will be performed in patients with CV disease confirmed on previous assessment.

Heart failure

HF is a dynamic syndrome characterized by gradual deterioration and episodic, acute exacerbations. TTE is the imaging modality of choice for follow-up of HF to determine progression or response to treatment, focussing on ventricular volumes, function, associated valve disease and PH.[5] TTE is used to investigate symptoms, acute or chronic deterioration and to determine prognosis, the latter being important to inform decisions on treatment with devices or transplantation, and patient counselling with respect to end-of-life. Estimating prognosis takes into account age, aetiology, NYHA class and co-morbidities including renal failure, anaemia and hyperuricaemia, while integrating imaging variables such as ejection fraction, wall thickness, geometry and filling pattern.[70] The routine repeat assessment of ventricular function however, in the absence of changing clinical status or a change in treatment, is not warranted.

Indications for device therapy

TTE has a central role in selection of patients with symptomatic HF who may benefit from an implantable cardioverter-defibrillator for prevention of sudden cardiac death, based on LV ejection fraction (LVEF < 35%).[47] Although the decision to implant a cardiac resynchronization device is based primarily on QRS duration > 150 ms, TTE is used to quantify LVEF < 35% and thereby acts as a gate-keeper for appropriate device implantation. TTE may also identify patients with secondary mitral regurgitation who would benefit from implantation.[71] The role of TTE in those with borderline QRS duration 120–150 ms continues to be a source of debate.[72] TTE is not recommended for routine optimization of all resynchronization devices.

TTE is also acts as a gate-keeper to select suitable candidates with end-stage heart failure for mechanical circulatory support, based on both LVEF <25% and on identification of right ventricular dysfunction. Repeat TTE in patients with mechanical circulatory support is useful, not only to optimize function and trouble-shoot complications but also to monitor response, with a view either to removal of the assist device (bridge to recovery) or to listing for transplantation (bridge to candidacy).[51] TTE may be indicated early post-implantation when PEff and tamponade are suspected, and whenever there is a suspicion of device-related infection.

Cardiactransplantation

The International Society for Heart and Lung Transplantation recommends the use of TTE for pre-operative assessment of the donor and recipient. TTE measurement of ventricular function is a component of the Heart Failure Survival Score, which identifies cut-points for transplant listing.[73] While TTE is used in the early post-transplant phase to monitor right ventricular function and tricuspid regurgitation, longer term routine TTE to monitor rejection is not considered useful as an alternative to endomyocardial biopsy.[74] TTE is commonly used however, when there is a clinical suspicion of acute allograft rejection and a baseline TTE is performed at least 6 months from the transplantation and then following endomyocardial biopsies, usually every 6 months.[75]

Ischaemic heart disease

There is no indication for use of TTE on a regular basis in patients with stable CAD in the absence of a change in clinical status. Sudden deterioration with recurrence of chest pain or other evidence of clinical compromise should trigger re-evaluation, specifically searching

Table 3 Clinical scenarios for repeat echocardiography following a first study

Scenario	Potential scenarios for repeat TTE	Focus of assessment
Heart failure	Change in HF status, prognosis, therapeutic decisions, including selection for device therapy, pharmacotherapy and transplant	LV size and function, RV size and function
Valvular heart disease	Progression of VHD, prosthetic valve assessment, pregnancy in context of VHD	Valve assessment, haemodynamic consequences, including LV size and function, RV size and function.
Infective endocarditis	Repeat following negative study with high clinical suspicion, change in clinical status in proven IE	Valve assessment, haemodynamic consequences including LV size and function, RV size and function, aorta, pericardium
Cardiomyopathy	Inherited and reversible cardiomyopathies.	LV size and function, RV size and function, response to treatment, complications specific to conditions
Pericardial disease	Pericardial effusion (change in clinical condition, response to intervention), pericardial constriction and predisposition	Pericardium and haemodynamic consequences of compromise
Patients at risk of CV disease	Genetic predisposition to cardiac disease, exposure to cardiotoxic medications (follow-up)	LV size, wall thickness and function, including advanced characterization of diastolic function and deformation, RV size and function
Adult congenital heart disease	Broad range of inherited conditions with de novo presentation or previous surgery	Valve and ventricular morphology and function, intracardiac pressure
Following device therapy	Early following pacing, resynchronization and cardio-defibrillator therapy, percutaneous valve interventions, appendage occlusions, complex percutaneous coronary intervention	LV size and function, RV size and function, valve function, pericardium

for evidence of progressive LV dysfunction or mechanical complications.[17]

Valvular heart disease

Asymptomatic patients with VHD need to be regularly re-assessed for change in ventricular size and function, as well as estimation of the likelihood of PH regardless of symptoms. The frequency of a repeat TTE is based on the type and severity of the valve lesion, the suspected rate of progression, and the haemodynamic consequences of the valve lesion.

Aortic regurgitation

A decrease in LVEF $\leq$ 50% or enlargement of the LV internal dimension (LVEDD >70 mm; LVESD >50 mm) in asymptomatic patients with severe AR determines poor survival after aortic valve replacement, demanding regular TTE. Serial follow-up is recommended 6-months after first assessment and then at yearly intervals if stable for severe AR, and every 2 years in patients with mild or moderate AR.[27,76]

Aortic stenosis

AS is progressive but there is marked individual variability. Assessment of asymptomatic severe AS is recommended every 6 months with TTE to detect LVEF <50%, velocity >5.5 m/s or progression in peak velocity >0.3 m/s/year. In those with mild or moderate AS, re-evaluation is recommended yearly but with intervals extended to 2–3 years in those without significant calcification.[27]

Bicuspid aortopathy and valve disease (BAV)

Patients with BAV can experience a more rapid progression of valve degeneration and also are at increased risk of thoracic aortic disease. In those with a normal aortic root, annual TTE may be adequate but in those with an increase in aortic dimensions > 3 mm/year or >45 mm, regular measurement with another imaging modality specifically for the aorta is indicated.[65]

Mitral stenosis (MS)

MS is a progressive disease and serial follow-up with TTE is indicated to identify MV area < 1.5 cm^2 (by 3D where feasible) and PH (resting PASP > 50 mmHg) that are indicators for intervention. TTE may also guide introduction of anti-coagulation in sinus rhythm when there is spontaneous contrast or LA dilatation >50 mm. Annual TTE should be performed in asymptomatic severe MS but at 2–3 years in those with a MV area $\geq$ 1.5 cm^2.[27]

Mitral regurgitation (MR)

TTE is essential to monitor increase in LV size (LVESD >45 mm), fall in LVEF <60%, PH (PASP >50 mmHg) and LA size (volume >60 mL/m^2) on an annual basis in asymptomatic severe MR. Asymptomatic patients with moderate MR and preserved LV function can be followed up with TTE every 2 years, and every 3 to 5 years in those with mild MR.[27,76]

Tricuspid valve (TV) disease

Patients with severe TV disease should be re-assessed on an annual basis, although CMR or 3D echocardiography should ideally be used

for surveillance of RV size and function.[27,76] In those with persistent or recurrent TR following left-sided valve surgery, regular re-assessment is warranted dependent on severity, ventricular size and function, and likelihood of right heart surgery.

Prosthetic valves

An initial TTE performed within 4–6 weeks of valve implantation is recommended in all patients after surgery or percutaneous intervention to serve as a baseline for future comparisons.[77] In patients with mechanical valve prostheses, routine annual echocardiographic evaluation is not necessary if the postoperative baseline study is normal and there is no change in clinical status. Routine, annual TTE is recommended however in bioprosthetic valves 5 years after implantation due to the risk of degeneration. Earlier evaluation may be prudent in selected patients at increased risk of early bioprosthetic valve degeneration, including those with renal impairment, diabetes mellitus, abnormal calcium metabolism, systemic inflammatory disease, and in patients <60 years of age. Onset of HF, systemic thrombo-embolism, haemolysis, or a new murmur on auscultation should raise the suspicion of prosthetic valve dysfunction and necessitates TTE examination.[27] Asymptomatic patients with prosthetic valve regurgitation or stenosis need more frequent follow-up for evidence of progressive LV dilatation and systolic dysfunction with the same criteria for timing of surgical intervention as those for native valve regurgitation. TTE is less sensitive than TEE for the evaluation of the cause of prosthetic valve dysfunction.

Pregnancy during follow-up of VHD

Pre-pregnancy evaluation of valve function, ventricular size and function, and pulmonary pressures is warranted in women with known VHD. In those who are pregnant, stenotic lesions carry a higher pregnancy risk than regurgitant lesions, with left-sided VHD a higher complication rate than right-sided lesions. Monthly TTE is therefore recommended in left-sided stenosis, while frequency should be individualized in those patients with regurgitation.[78] In those who are pregnant with mechanical prostheses, monthly TTE is recommended, with additional imaging performed in a patient with any type of prosthesis if breathless or with evidence of emboli.

Infective endocarditis

Repeat TTE within 7–10 days is recommended in cases of initially negative examination when clinical suspicion of IE remains high, particularly in the presence of prosthetic material. Repeat TTE is mandatory in patients with IE who have worsening or persisting symptoms, and in patients at high risk of complications including HF, valve failure, peri-valvular extension, and embolism.[79] In such patients, the aim of TTE is to identify a subgroup of patients who may benefit from early surgery.[80] In stable patients with IE, the benefit of routine repeat TTE is not proven. There is no evidence of benefit from routine repeat TTE after completion of antibiotic therapy but TTE is recommended at discharge as a baseline for future comparisons in case of suspected recurrent IE, particularly in those who have undergone surgery.

Cardiomyopathy
HCM

There is a life-long process of progressive, adverse cardiac remodelling in HCM including change in systolic and diastolic function, wall thickness, cavity size, and outflow tract gradient.[30] The variability of the disease means that annual or bi-annual TTE should be considered to monitor potential changes in morphology and function as well as in risk profile.[81] Repeat TTE is warranted when there is also a change in clinical status. Repeat TTE has a role in the assessment of response to medical, percutaneous and interventional treatment of HCM, particularly in the management of LV outflow tract obstruction.[66]

DCM, ARVC, RCM

Although these are progressive diseases, there are no data on which to base a recommendation for routine surveillance with TTE in stable patients without a change in clinical status. Principles that are valid for HF patients are to be followed until new evidence is available for these patients, although it is common practice to perform annual TTE. LVNC should be present from birth but other conditions can mimic LVNC and these may progress over time. Furthermore, in those with known LVNC it is common practice to perform annual TTE to follow onset and progression of heart failure.

Reversible cardiomyopathies

Peripartum CM, tachycardia-induced CM and Tako-tsubo CM are potentially reversible, often within 6 months. TTE is helpful to monitor response to treatment and to detect complications, including RV involvement, thrombus formation, and MR. While no firm data exist for timing follow-up TTE, there is support for imaging at 3 and/or 6 months depending on local availability and patient clinical status.[82]

Pericardial disease
Acute pericarditis

A first episode of acute pericarditis is expected to subside with appropriate treatment within 7 days and while TTE should be performed once in suspected cases, repeat study is not needed unless there are complications, including a moderate or large effusion, tamponade, failure to respond to therapy, or persisting fever and chest pain >1 week.[16] Restriction of exercise should be considered for those with acute pericarditis until resolution of symptoms, ECG and TTE abnormalities if present.

Recurrent pericarditis

This usually occurs within 1–3 months of the initial episode but PEff is less common than in the acute phase and there is no consensus on the optimal frequency of repeat TTE.

Pericardial effusion (PEff)

TTE is the primary imaging modality for surveillance of PEff. Repeat TTE is useful to guide drainage, determining duration of an indwelling drain, and to monitor recurrence. Frequency of repeat TTE should be guided by clinical status. In asymptomatic individuals with chronic PEff, there are no data to indicate how often an echocardiogram should be repeated.[83] Auto-reactive pericarditis and asymptomatic PEff are common in systemic autoimmune diseases, including rheumatoid arthritis and systemic lupus erythematosus, yet the

frequency with which screening TTE should be performed is not clear in the absence of clinical concern.

Pericardial constriction (PC)

Suspicion is raised in patients with signs of predominantly right-sided heart failure although in the majority PC is a chronic condition that is often diagnosed late. TTE is recommended 5 years after exposure in those who are at high risk for radiotherapy-induced heart disease and 10 years after exposure in others.[84] Repeat TTE is recommended in patients following pericardiocentesis, medical treatment or pericardiotomy in effusive-constrictive pericarditis and transient PC.[83]

Aortic disease

While TTE is useful for evaluating the aortic root and proximal ascending aorta, CT or MRI are preferred for routine surveillance of thoracic aortic dimensions.[20] CT or MRI are also recommended for routine surveillance following aortic dissection, intramural haemorrhage and penetrating aortic ulcer. TTE can be used for routine follow-up in Marfan syndrome and BAV-associated aortopathy but only when dilatation is restricted to the root and proximal ascending aorta, and when concordance between the dimensions measured by TTE and CT or MRI has been documented.[20]

Repeat echocardiography in the assessment of the patient at risk of cardiac disease

Hypertension

Repeat TTE to monitor for onset of CV complications of hypertension in the absence of symptoms or signs is not recommended and there is no role in evaluating response to treatment.[60] Conversely, repeat TTE should be performed if there is a change in clinical status or with poor control of blood pressure.[85]

Risk factors and asymptomatic adults

There is no incremental benefit to history and clinical risk estimation in repeat TTE in asymptomatic individuals with or without DM, dyslipidaemias or other risk factors for CAD.

Genetic predisposition and screening

In first-degree relatives of patients with HCM in whom genetic status is unknown, clinical assessment with ECG and TTE should be considered every 1–2 years between 10 and 20 years of age, and every 5 years thereafter (12 monthly if non-diagnostic abnormalities are present) as late-onset hypertrophy can occur.[86] First-degree relatives who do not share the same disease-causing mutation as the proband should be discharged from further follow-up.

First-degree relatives of patients with other CM including ARVC, DCM, and RCM not known to be affected should undergo periodic TTE in those cases where genetic testing is not categorical and where late occurrence may arises. Screening every 5 years may be reasonable. LVNC should be present from birth and no late occurrence is to be expected.

Cardiotoxic therapy

Evaluation by TTE of ventricular size and function is recommended before, during, and after cancer therapy. 3DE is the preferred technique for monitoring LV function, although 2D TTE measurement of global longitudinal strain is recognized as a more sensitive means of detecting subclinical LV dysfunction during follow-up studies.[49] For low dose type I toxicity, for example doxorubicin, repeat TTE is recommended at the completion of therapy and 6 months later. For patients exposed to type II toxicity, for example trastuzumab, repeat TTE is recommended every 3 months during therapy and at 6 months following completition of therapy.

Adult congenital heart disease

TTE is the primary imaging tool in the on-going management of the adult with congenital heart disease. It is used to measure and follow-up valve and ventricular function, ventricular mass, calculate pulmonary pressure, and monitor intracardiac shunts. Special competency in ACHD is important in TTE in this group of patients, particularly as imaging becomes complicated by the super-imposition of acquired disease with age. Frequency of repeat TTE should be decided on the basis of type of congenital abnormality, type and result of surgical correction, the individual's clinical condition and prognosis, and the availability of local medical services.[67,68] In general, annual TTE should be performed in any asymptomatic, clinically stable patient following incomplete or palliative repair, for example Tetralogy of Fallot. In any asymptomatic patient following complete repair without residual structural or haemodynamic abnormality, there is no clear evidence of benefit from regular repeat TTE. TTE should be performed in any patient with documented ACHD to investigate a change in clinical status or examination and to guide therapy.

Following device therapy and intervention

There is increasing demand for TTE not only in the identification of patients suitable for device therapy and intervention but for following such patients after therapy. While it is common practice to monitor implantation or exclude immediate and early complications, there are very limited data however that demonstrate improved patient care directly as a result of regular, repeat echocardiography following device therapy and intervention.

Pacing, resynchronization, and cardio-defibrillator therapy

The majority of complications from implantation of pacemakers, resynchronization devices and cardio-defibrillators occur in-hospital or within the first 6-weeks.[87] TTE should be performed in all patients soon following implantation to exclude mechanical complications, including PEff, and to check on lead placement. There is no evidence to support further echocardiography unless there is clinical concern regarding complications such as device-related infection.

Transcatheter valve and device therapy

Early assessment with echocardiography within 24 hrs following transcatheter valve intervention is recommended, whether or not peri-procedural echocardiography is performed during the procedure itself. The aim is to confirm function of the valve, exclude complications including paravalvar regurgitation and pericardial effusion, and to act as a baseline for future comparison not only of the new device but also of ventricular and other valve function.[88] Thereafter, for

transcatheter aortic valve implantation, follow-up evaluation is recommended as for surgically-implanted bioprostheses but additional, repeat assessment of transcatheter mitral valve intervention is recommended at 6 months specifically to assess reverse ventricular remodelling.[88]

For transcatheter repair of paravalvar regurgitation, peri-procedural echocardiography is required but early assessment by TTE within 24 hrs should also be performed to exclude complications and as a baseline for future reference. Additional repeat echocardiography thereafter may be performed as planned for the prosthetic valve itself with no additional imaging required without a clinical suspicion of complications.

Following transcatheter or device occlusion of the left atrial appendage, follow-up echocardiography is performed within the first month, at 6 months and then annually to ensure device stability, absence of leak and to exclude associated complications.[89]

Revascularization for IHD

There is no evidence to support routine TTE following percutaneous revascularization.[90] The rationale for and timing of echocardiography in patients with stable angina and ACS has been discussed but repeat imaging following percutaneous revascularization is not necessary unless the patient has had a complicated course, for example suspected peri-procedural myocardial infarction, dissection or guidewire perforation. TTE should be performed as baseline prior to discharge following surgical revascularization.

Conclusions

Indications for TTE in the adult continue to grow and activity in many departments across Europe increases inexorably. TTE is operator dependent and it is vital that the test is performed by qualified individuals within proficient departments that monitor quality.[91,92] Demand for TTE and the costs that arise from providing high quality imaging necessitates that there is a clear incremental benefit to the patient and the healthcare system from the performance of the test beyond history and examination, taking into account other imaging modalities. The degree of benefit will be subject to change and indications will need to be subject to regular review.

Conflict of interest: None declared.

References

1. Sonderegger-Iseli K, Burger S, Muntwyler J, Salomon F. Diagnostic errors in three medical eras: a necropsy study. *Lancet* 2000;**355**:2027–31.
2. Papolos A, Narula J, Bavishi C, Chaudhry FA, Sengupta PP. U.S. hospital use of echocardiography: insights from the nationwide inpatient sample. *J Am Coll Cardiol* 2016;**67**:502–11.
3. Nolan JP, Soar J, Zideman DA, Biarent D, Bossaert LL, Deakin C et al. European resuscitation council guidelines for resuscitation 2010 section 1. Executive summary. *Resuscitation* 2010;**81**:1219–76.
4. Lancellotti P, Price S, Edvardsen T, Cosyns B, Neskovic AN, Dulgheru R et al. The use of echocardiography in acute cardiovascular care: recommendations of the European association of cardiovascular imaging and the acute cardiovascular care association. *Eur Heart J–Cardiovasc Imaging* 2015;**16**:119–46.
5. Ponikowski P, Voors AA, Anker SD, Bueno H, Cleland JGF, Coats AJS et al. ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J* 2016;**37**:2129–200.
6. Sicari R, Galderisi M, Voigt J-U, Habib G, Zamorano JL, Lancellotti P et al. The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography. *Eur Heart J–Cardiovasc Imaging* 2011;**12**:85–7.
7. Neskovic AN, Edvardsen T, Galderisi M, Garbi M, Gullace G, Jurcut R et al. Focus cardiac ultrasound: the European Association of Cardiovascular Imaging viewpoint. *Eur Heart J–Cardiovasc Imaging* 2014;**15**:956–60.
8. Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW et al. International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med* 2012;**38**:577–91.
9. Torbicki A, Galie N, Covezzoli A, Rossi E, De Rosa M, Goldhaber SZ. Right heart thrombi in pulmonary embolism: results from the International Cooperative Pulmonary Embolism Registry. *J Am Coll Cardiol* 2003;**41**:2245–51.
10. Konstantinides SV, Torbicki A, Agnelli G, Danchin N, Fitzmaurice D, Galiè N et al. 2014 ESC Guidelines on the diagnosis and management of acute pulmonary embolism. *Eur Heart J* 2014;**35**:3033–73.
11. Roy P-M, Colombet I, Durieux P, Chatellier G, Sors H, Meyer G. Systematic review and meta-analysis of strategies for the diagnosis of suspected pulmonary embolism. *BMJ*. 2005;**331**:259.
12. Pruszczyk P, Goliszek S, Lichodziejewska B, Kostrubiec M, Ciurzynski M, Kurnicka K et al. Prognostic value of echocardiography in normotensive patients with acute pulmonary embolism. *JACC Cardiovasc Imaging* 2014;**7**:553–60.
13. Meyer G, Vicaut E, Danays T, Agnelli G, Becattini C, Beyer-Westendorf J et al. Fibrinolysis for patients with intermediate-risk pulmonary embolism. *NEJM* 2014;**370**:1402–11.
14. Frassi F, Gargani L, Gligorova S, Ciampi Q, Mottola G, Picano E. Clinical and echocardiographic determinants of ultrasound lung comets. *Eur Heart J–Cardiovasc Imaging* 2007;**8**:474–9.
15. Hamm CW, Bassand J-P, Agewall S, Bax J, Boersma E, Bueno H et al. ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. *Eur Heart J* 2011;**32**:2999–3054.
16. Adler Y, Charron P, Imazio M, Badano L, Barón-Esquivias G, Bogaert J et al. 2015 ESC Guidelines for the diagnosis and management of pericardial diseases. *Eur Heart J* 2015;**36**:2921–64.
17. Steg PG, James SK, Atar D, Badano LP, Blomstrom-Lundqvist C, Borger MA et al. ESC Guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation. *Eur Heart J* 2012;**33**:2569–619.
18. Tong KL, Kaul S, Wang X-Q, Rinkevich D, Kalvaitis S, Belcik T et al. Myocardial contrast echocardiography versus thrombolysis in myocardial infarction score in patients presenting to the emergency department with chest pain and a nondiagnostic electrocardiogram. *J Am Coll Cardiol* 2005;**46**:920–7.
19. Grenne B, Eek C, Sjøli B, Dahlslett T, Uchto M, Hol PK et al. Acute coronary occlusion in non-ST-elevation acute coronary syndrome: outcome and early identification by strain echocardiography. *Heart* 2010;**96**:1550–6.
20. Goldstein SA, Evangelista A, Abbara S, Arai A, Asch FM, Badano LP et al. Multimodality imaging of diseases of the thoracic aorta in adults: from the American Society of Echocardiography and the European Association of Cardiovascular Imaging: endorsed by the Society of Cardiovascular Computed Tomography and Society for Cardiovascular Magnetic Resonance. *J Am Soc Echocardiogr* 2015;**28**:119–82.
21. Sybrandy KC, Cramer MJM, Burgersdijk C. Diagnosing cardiac contusion: old wisdom and new insights. *Heart* 2003;**89**:485–9.
22. Nagueh SF, Smiseth OA, Appleton CP, Byrd BF III, Dokainish H, Edvardsen T et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography: an update from the American society of echocardiography and the European association of cardiovascular imaging. *J Am Soc Echocardiogr* 2016;**29**:277–314.
23. Januzzi JL Jr, Camargo CA, Anwaruddin S, Baggish AL, Chen AA, Krauser DG et al. The N-terminal Pro-BNP investigation of dyspnea in the emergency department (PRIDE) study. *Am J Cardiol* 2005;**95**:948–54.
24. Baggish AL, van Kimmenade RR, Januzzi JL Jr. The differential diagnosis of an elevated amino-terminal pro-B-type natriuretic peptide level. *Am J Cardiol* 2008;**101**:43–8.
25. Kristensen SD, Knuuti J, Saraste A, Anker S, Børker HE, Hert SD et al. 2014 ESC/ESA Guidelines on non-cardiac surgery: cardiovascular assessment and management. *Eur Heart J* 2014;**35**:2383–431.
26. Spencer KT, Anderson AS, Bhargava A, Bales AC, Sorrentino M, Furlong K et al. Physician-performed point-of-care echocardiography using a laptop platform compared with physical examination in the cardiovascular patient. *J Am Coll Cardiol* 2001;**37**:2013–8.
27. Vahanian A, Alfieri O, Andreotti F, Antunes MJ, Baron-Esquivias G, Baumgartner H et al. Guidelines on the management of valvular heart disease (version 2012). *Eur Heart J* 2012;**33**:2451–96.
28. Elliott P, Andersson B, Arbustini E, Bilinska Z, Cecchi F, Charron P et al. Classification of the cardiomyopathies: a position statement from the European Society of Cardiology Working Group on Myocardial and Pericardial diseases. *Eur Heart J* 2008;**29**:270–6.
29. Galderisi M, Cardim N, D'Andrea A, Bruder O, Cosyns B, Davin L et al. The multi-modality cardiac imaging approach to the Athlete's heart: an expert

consensus of the European Association of Cardiovascular Imaging. *Eur Heart J–Cardiovasc Imaging* 2015;**16**:353–r.

30. Cardim N, Galderisi M, Edvardsen T, Plein S, Popescu BA, D'Andrea A et al. Role of multimodality cardiac imaging in the management of patients with hypertrophic cardiomyopathy: an expert consensus of the European Association of Cardiovascular Imaging Endorsed by the Saudi Heart Association. *Eur Heart J Cardiovasc Imaging* 2015;**16**:280.

31. Marcus FI, McKenna WJ, Sherrill D, Basso C, Bauce B, Bluemke DA et al. Diagnosis of arrhythmogenic right ventricular cardiomyopathy/dysplasia. *Circulaton* 2010;**121**:1533–41.

32. Dungu JN, Anderson LJ, Whelan CJ, Hawkins PN. Cardiac transthyretin amyloidosis. *Heart* 2012;**98**:1546–54.

33. Parshall MB, Schwartzstein RM, Adams L, Banzett RB, Manning HL, Bourbeau J et al. An official American Thoracic Society statement: update on the mechanisms, assessment, and management of dyspnea. *Am J Respir Crit Care Med* 2012;**185**:435–52.

34. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K et al. Guidelines for the Echocardiographic Assessment of the Right Heart in Adults: a report from the American Society of Echocardiography: endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. *J Am Soc Echocardiogr* 2010;**23**:685–713.

35. Grifoni S, Olivotto I, Cecchini P, Pieralli F, Camaiti A, Santoro G et al. Short-term clinical outcome of patients with acute pulmonary embolism, normal blood pressure, and echocardiographic right ventricular dysfunction. *Circulation* 2000;**101**:2817–22.

36. Grifoni S, Vanni S, Magazzini S, Olivotto I, Conti A, Zanobetti M et al. Association of persistent right ventricular dysfunction at hospital discharge after acute pulmonary embolism with recurrent thromboembolic events. *Arch Int Med* 2006;**166**:2151–6.

37. Galiè N, Humbert M, Vachiery J-L, Gibbs S, Lang I, Torbicki A et al. 2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension. *Eur Heart J* 2016;**37**:67–119.

38. Roffi M, Patrono C, Collet J-P, Mueller C, Valgimigli M, Andreotti F et al. 2015 ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. *Eur Heart J* 2016;**37**:267–315.

39. Sabia P, Abbott RD, Afrookteh A, Keller MW, Touchstone DA, Kaul S. Importance of two-dimensional echocardiographic assessment of left ventricular systolic function in patients presenting to the emergency room with cardiac-related symptoms. *Circulation* 1991;**84**:1615–24.

40. Fleischmann KE, Lee RT, Come PC, Goldman L, Cook EF, Weissman MA et al. Impact of valvular regurgitation and ventricular dysfunction on long-term survival in patients with chest pain. *Am J Cardiol* 1997;**80**:1266–72.

41. Daly CA, De Stavola B, Sendon JLL, Tavazzi L, Boersma E, Clemens F et al. Predicting prognosis in stable angina—results from the Euro heart survey of stable angina: prospective observational study. *BMJ* 2006;**332**:262–7.

42. O'Mahony MS, Sim MFV, Ho SF, Steward JA, Buchalter M, Burr M. Diastolic heart failure in older people. *Age Age.* 2003;**32**:519–24.

43. Imazio M, Cecchi E, Demichelis B, Ierna S, Demarie D, Ghisio A et al. Indicators of poor prognosis of acute pericarditis. *Circulation* 2007;**115**:2739–44.

44. Moya A, Sutton R, Ammirati F, Blanc J-J, Brignole M, Dahm JB et al. Guidelines for the diagnosis and management of syncope (version 2009). *Eur Heart J* 2009;**30**:2631–71.

45. Raviele A, Giada F, Bergfeldt L, Blanc JJ, Blomstrom-Lundqvist C, Mont L et al. Management of patients with palpitations: a position paper from the European Heart Rhythm Association. *Europace* 2011;**13**:920–34.

46. Donal E, Lip GYH, Galderisi M, Goette A, Shah D, Marwan M et al. EACVI/EHRA Expert Consensus Document on the role of multi-modality imaging for the evaluation of patients with atrial fibrillation. *Eur Heart J–Cardiovasc Imaging* 2016;**17**:355–83.

47. Priori SG, Blomström-Lundqvist C, Mazzanti A, Blom N, Borggrefe M, Camm J et al. 2015 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death. *Eur Heart J* 2015;**36**:2793–867.

48. Thygesen K, Mair J, Giannitsis E, Mueller C, Lindahl B, Blankenberg S et al. How to use high-sensitivity cardiac troponins in acute cardiac care. *Eur Heart J* 2012;**33**:2252–7.

49. Plana JC, Galderisi M, Barac A, Ewer MS, Ky B, Scherrer-Crosbie M et al. Expert consensus for multimodality imaging evaluation of adult patients during and after cancer therapy: a report from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J–Cardiovasc Imaging* 2014;**15**:1063–93.

50. Lancellotti P, Nkomo VT, Badano LP, Bergler-Klein J, Bogaert J, Davin L et al. Expert consensus for multi-modality imaging evaluation of cardiovascular complications of radiotherapy in adults: a report from the European Association of Cardiovascular Imaging and the American Society of Echocardiography. *Eur Heart J–Cardiovasc Imaging* 2013;**14**:721–40.

51. McMurray JJV, Adamopoulos S, Anker SD, Auricchio A, Böhm M, Dickstein K et al. ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure 2012. *Eur Heart J* 2012;**33**:1787–847.

52. Loomba RS, Shah PH, Nijhawan K, Aggarwal S, Arora R. Cardiothoracic ratio for prediction of left ventricular dilation: a systematic review and pooled analysis. *Future Cardiol* 2015;**11**:171–5.

53. Habib G, Lancellotti P, Antunes MJ, Bongiorni MG, Casalta J-P, Del Zotti F et al. 2015 ESC Guidelines for the management of infective endocarditis. *Eur Heart J* 2015;**36**:3075–128.

54. Rasmussen RV, Høst U, Arpi M, Hassager C, Johansen HK, Korup E et al. Prevalence of infective endocarditis in patients with Staphylococcus aureus bacteraemia: the value of screening with echocardiography. *Eur J Echocardiogr* 2011;**12**:414–20.

55. Pepi M, Evangelista A, Nihoyannopoulos P, Flachskampf FA, Athanassopoulos G, Colonna P et al. Recommendations for echocardiography use in the diagnosis and management of cardiac sources of embolism: European Association of Echocardiography (EAE) (a registered branch of the ESC). *Eur J Echocardiogr* 2010;**11**:461–76.

56. Kurt M, Shaikh KA, Peterson L, Kurrelmeyer KM, Shah G, Nagueh SF et al. Impact of contrast echocardiography on evaluation of ventricular function and clinical management in a large prospective cohort. *J Am Coll Cardiol* 2009;**53**:802–10.

57. Meier B, Kalesan B, Mattle HP, Khattab AA, Hildick-Smith D, Dudek D et al. Percutaneous closure of patent foramen ovale in cryptogenic embolism. *NEJM* 2013;**368**:1083–91.

58. Carroll JD, Saver JL, Thaler DE, Smalling RW, Berry S, MacDonald LA et al. Closure of patent foramen ovale versus medical therapy after cryptogenic stroke. *NEJM* 2013;**368**:1092–100.

59. Bruce CJ. Cardiac tumours: diagnosis and management. *Heart* 2011;**97**:151–60.

60. Marwick TH, Gillebert TC, Aurigemma G, Chirinos J, Derumeaux G, Galderisi M et al. Recommendations on the use of echocardiography in adult hypertension: a report from the European Association of Cardiovascular Imaging (EACVI) and the American Society of Echocardiography (ASE). *Eur Heart J–Cardiovasc Imaging* 2015;**16**:577–605.

61. Piepoli MF, Hoes AW, Agewall S, Albus C, Brotons C, Catapano AL et al. 2016 European guidelines on cardiovascular disease prevention in clinical practice. *Eur Heart J* 2016;**37**:2315–81.

62. Rydén L, Grant PJ, Anker SD, Berne C, Cosentino F, Danchin N et al. ESC Guidelines on diabetes, pre-diabetes, and cardiovascular diseases developed in collaboration with the EASD. *Eur Heart J* 2014;**35**:1824.

63. Reiner Z, Catapano AL, De Backer G, Graham I, Taskinen MR, Wiklund O et al. ESC/EAS Guidelines for the management of dyslipidaemias: the Task Force for the management of dyslipidaemias of the European Society of Cardiology (ESC) and the European Atherosclerosis Society (EAS). *Eur Heart J* 2011;**32**:1769–818.

64. Greenland P, Alpert JS, Beller GA, Benjamin EJ, Budoff MJ, Fayad ZA et al. 2010 ACCF/AHA guideline for assessment of cardiovascular risk in asymptomatic adults. *J Am Coll Cardiol* 2010;**56**:2182–99.

65. Erbel R, Aboyans V, Boileau C, Bossone E, Bartolomeo RD, Eggebrecht H et al. 2014 ESC Guidelines on the diagnosis and treatment of aortic diseases: document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). *Eur Heart J* 2014;**35**:2873–926.

66. Elliott PM, Anastasakis A, Borger MA, Borggrefe M, Cecchi F, Charron P et al. 2014 ESC guidelines on diagnosis and management of hypertrophic cardiomyopathy. *Eur Heart J* 2014;**35**:2733–79.

67. Bhatt AB, Foster E, Kuehl K, Alpert J, Brabeck S, Crumb S et al. Congenital heart disease in the older adult: a scientific statement from the American heart association. *Circulation* 2015;**131**:1884–931.

68. Baumgartner H, Bonhoeffer P, De Groot NMS, de Haan F, Deanfield JE, Galie N et al. ESC Guidelines for the management of grown-up congenital heart disease. *Eur Heart J* 2010;**31**:2915–57.

69. Wharton G, Steeds R, Allen J, Phillips H, Jones R, Kanagala P et al. A minimum dataset for a standard adult transthoracic echocardiogram: a guideline protocol from the British Society of Echocardiography. *Echo Res Pract* 2015;**2**:G9–24.

70. Cikes M, Solomon SD. Beyond ejection fraction: an integrative approach for assessment of cardiac structure and function in heart failure. *Eur Heart J* 2015;**37**:1642–50.

71. Spartera M, Galderisi M, Mele D, Cameli M, D'Andrea A, Rossi A et al. Role of cardiac dyssynchrony and resynchronization therapy in functional mitral regurgitation. *Eur Heart J–Cardiovasc Imaging* 2016;**17**:471–80.

72. Khan SG, Klettas D, Kapetanakis S, Monaghan MJ. Clinical utility of speckle-tracking echocardiography in cardiac resynchronisation therapy. *Echo Res Pract* 2016;**3**:R1–11.

73. Mehra MR, Canter CE, Hannan MM, Semigran MJ, Uber PA, Baran DA *et al.* The 2016 international society for heart lung transplantation listing criteria for heart transplantation: a 10-year update. *J Heart Lung Transpl* **35**:1–23.

74. Costanzo MR, Dipchand A, Starling R, Anderson A, Chan M, Desai S *et al.* The International Society of Heart and Lung Transplantation Guidelines for the care of heart transplant recipients. *J Heart Lung Transpl* 2010;**29**:914–56.

75. Badano LP, Miglioranza MH, Edvardsen T, Colafranceschi AS, Muraru D, Bacal F *et al.* European Association of Cardiovascular Imaging/Cardiovascular Imaging Department of the Brazilian Society of Cardiology recommendations for the use of cardiac imaging to assess and follow patients after heart transplantation. *Eur Heart J–Cardiovasc Imaging* 2015;**16**:919–48.

76. Lancellotti P, Tribouilloy C, Hagendorff A, Popescu BA, Edvardsen T, Pierard LA *et al.* Recommendations for the echocardiographic assessment of native valvular regurgitation: an executive summary from the European Association of Cardiovascular Imaging. *Eur Heart J–Cardiovasc Imaging* 2013;**14**:611–44.

77. Lancellotti P, Pibarot P, Chambers J, Edvardsen T, Delgado V, Dulgheru R *et al.* Recommendations for the imaging assessment of prosthetic heart valves: a report from the European Association of Cardiovascular Imaging endorsed by the Chinese Society of Echocardiography, the Inter-American Society of Echocardiography, and the Brazilian. *Eur Heart J–Cardiovasc Imaging* 2016;**17**:589–90.

78. Regitz-Zagrosek V, Blomstrom Lundqvist C, Borghi C, Cifkova R, Ferreira R, Foidart JM *et al.* ESC Guidelines on the management of cardiovascular diseases during pregnancy: the Task Force on the Management of Cardiovascular Diseases during Pregnancy of the European Society of Cardiology (ESC). *Eur Heart J* 2011;**32**:3147–97.

79. Habib G, Badano L, Tribouilloy C, Vilacosta I, Zamorano JL, Galderisi M *et al.* Recommendations for the practice of echocardiography in infective endocarditis. *Eur J Echocardiogr* 2010;**11**:202–19.

80. Kang D-H, Kim Y-J, Kim S-H, Sun BJ, Kim D-H, Yun S-C *et al.* Early surgery versus conventional treatment for infective endocarditis. *NEJM* 2012;**366**:2466–73.

81. O'Mahony C, Jichi F, Pavlou M, Monserrat L, Anastasakis A, Rapezzi C *et al.* A novel clinical risk prediction model for sudden cardiac death in hypertrophic cardiomyopathy (HCM risk-SCD). *Eur Heart J* 2014;**35**:2010–20.

82. Bossone E, Lyon A, Citro R, Athanasiadis A, Meimoun P, Parodi G *et al.* Takotsubo cardiomyopathy: an integrated multi-imaging approach. *Eur Heart J–Cardiovasc Imaging* 2014;**15**:366–77.

83. Cosyns B, Plein S, Nihoyanopoulos P, Smiseth O, Achenbach S, Andrade MJ *et al.* European Association of Cardiovascular Imaging (EACVI) position paper: multimodality imaging in pericardial disease. *Eur Heart J–Cardiovasc Imaging* 2015;**16**:12–31.

84. Villarraga HR, Herrmann J, Nkomo VT. Cardio-oncology: role of echocardiography. *Progr Cardiovasc Dis* 2014;**57**:10–8.

85. Mancia G, Fagard R, Narkiewicz K, Redon J, Zanchetti A, Böhm M *et al.* 2013 ESH/ESC Guidelines for the management of arterial hypertension. *Eur Heart J* 2013;**34**:2159–219.

86. Charron P, Arad M, Arbustini E, Basso C, Bilinska Z, Elliott P *et al.* Genetic counselling and testing in cardiomyopathies: a position statement of the European Society of Cardiology Working Group on Myocardial and Pericardial Diseases. *Eur Heart J* 2010;**31**:2715–26.

87. Brignole M, Auricchio A, Baron-Esquivias G, Bordachar P, Boriani G, Breithardt OA *et al.* 2013 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy: the Task Force on cardiac pacing and resynchronization therapy of the European Society of Cardiology (ESC). Developed in collaboration with the European Heart Rhythm Association (EHRA). *Eur Heart J* 2013;**34**:2281–329.

88. Zamorano JL, Badano LP, Bruce C, Chan KL, Goncalves A, Hahn RT *et al.* EAE/ASE recommendations for the use of echocardiography in new transcatheter interventions for valvular heart disease. *Eur Heart J* 2011;**32**:2189–214.

89. Chue CD, de Giovanni J, Steeds RP. The role of echocardiography in percutaneous left atrial appendage occlusion. *Eur J Echocardiogr* 2011;**12**:i3–10.

90. Windecker S, Kolh P, Alfonso F, Collet JP, Cremer J, Falk V *et al.* 2014 ESC/EACTS Guidelines on myocardial revascularization: the Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS)Developed with the special contribution of the European Association of Percutaneous Cardiovascular Interventions (EAPCI). *Eur Heart J* 2014;**35**:2541–619.

91. Popescu BA, Andrade MJ, Badano LP, Fox KF, Flachskampf FA, Lancellotti P *et al.* European Association of Echocardiography recommendations for training, competence, and quality improvement in echocardiography. *Eur J Echocardiogr* 2009;**10**:893–905.

92. Popescu BA, Stefanidis A, Nihoyannopoulos P, Fox KF, Ray S, Cardim N *et al.* Updated standards and processes for accreditation of echocardiographic laboratories from The European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2014;**15**:717–27.