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INTRODUCTION

- Transthoracic echocardiography (TTE) uses ultrasound to image the complex structures of the heart in a real time format, providing 2-dimensional, cross sectional images.
- The addition of Doppler ultrasound derives hemodynamic data from flow velocity versus time measurements, as well as from color coded two dimensional representations of flow velocities.
- TTE's safety and versatility in examining cardiac structure, function, and hemodynamics lends to its utility for numerous indications in children and adults.
- TEE (transesophageal echocardiography) widens the scope of utility for echocardiographic imaging, and its indications are covered in a separate guideline.

ADULT PATIENTS

Indications for pediatric patients follow the section for adult patients.

Indications for Transthoracic Echocardiography (TTE)

(Douglas 2011)

General Evaluation of Cardiac Structure and Function
Suspected Cardiac Etiology
• Symptoms or conditions potentially related to suspected cardiac etiology including, but not limited to, chest pain, shortness of breath, palpitations, TIA, stroke, or peripheral embolic event • Respiratory failure or hypoxemia of uncertain etiology if cardiac structural or myocardial disease is a consideration • Prior testing that is concerning for heart disease or structural abnormality including but not limited to ECG, chest X-ray, baseline scout images from stress echocardiography, or cardiac biomarkers
Arrhythmias
• Frequent VPCs or exercise-induced VPCs • Atrial fibrillation, SVT, or VT

Presyncope/Syncope (Shen 2017; Benditt 2018; Doherty 2017)
• When clinical rationale supports a suspicion of structural or potentially structurally associated arrhythmic heart disease, i.e. a diagnosis known to cause such symptoms
Perioperative Evaluation (Fleischer 2014; Lentine 2012; Cowie 2010)
• Preoperative left ventricular function assessment in patients who are candidates for kidney or liver transplantation; TTE might identify pulmonary hypertension and/or intrapulmonary arteriovenous shunt in candidates for liver transplantation • Re-evaluation (<1 yr) in patients with moderate or severe aortic stenosis, who will be subjected to increased hemodynamic demands (e.g. noncardiac surgery, pregnancy) • Evaluation of patients prior to noncardiac surgery with clinically suspected moderate or greater degrees of valvular stenosis or regurgitation if there has been either o No prior echo within 1 year OR o There has been a significant change in clinical status or physical examination since the last evaluation.
Pulmonary Hypertension
• Evaluation of suspected pulmonary hypertension including evaluation of right ventricular function and estimated pulmonary artery pressure • Evaluation of pulmonary embolism patients with respect to right ventricular function and pulmonary hypertension, with intent to risk stratify and initiate appropriate therapy (Saric 2016). • Routine surveillance (≥1 y) of known pulmonary hypertension without change in clinical status or cardiac exam • Re-evaluation of known pulmonary hypertension if there is a change in clinical status or cardiac exam, or to guide therapy • Surveillance for pulmonary hypertension during chemotherapy with dasatinib, every 3 months during and again at completion of therapy, and as required for subsequent symptoms or signs of pulmonary hypertension (Zamorano 2016).
Evaluation of Valvular Function (Doherty 2017, Nishimura 2014)
INITIAL Evaluation of Valvular Function in an Asymptomatic Patient
• Asymptomatic patient with unexplained heart murmur or abnormal heart sounds, with reasonable suspicion of valvular heart disease • Continuous heart murmur (Warnes 2008) • History of rheumatic heart disease • Known systemic or acquired disease associated with valvular heart disease (Examples: Ankylosing spondylitis, Marfan's, Turner's, history tertiary syphilis, Ehlers Danlos or Loeys-Dietz syndromes, etc.) (Hiratzka 2010) • First degree family member has history of bicuspid aortic valve (Warnes 2008) • Patient with Turner syndrome, for evaluation of bicuspid aortic valve, as well as coarctation of the aorta and aortic root dilation • Exposure to medications that could result in development of valvular heart disease (Examples: The prior use of the diet drug fenfluramine/phentermine, marketed as

Fen Phen, and or dexphenfluramine alone, can cause aortic or mitral regurgitation. Bengluorex is another culprit diet drug. Ergot derivatives used for migraine, such as ergotamine and methysergide are a group. Bromocriptine (another ergot derivative) can cause valvular problems. Parkinson medications, such as pergolide and cabergoline are another group, both removed from the US market. Also, prior radiation to the heart valves can cause valvular disease. The vast majority of the disease is valvular regurgitation, mainly aortic, mitral, and tricuspid. There have even been reports of Ecstasy causing valvular regurgitation, but that appears to be less clear.)
Murmur or Click
• Initial evaluation when there is a reasonable suspicion of valvular or structural heart disease • Re-evaluation of known valvular heart disease with a change in clinical status or cardiac exam, or to guide therapy
Native Valvular Stenosis
• Routine surveillance (≥3 yr) of bicuspid aortic valve, aortic sclerosis, or mild valvular stenosis, without a change in clinical status or cardiac exam • Routine surveillance (≥1 yr) of moderate stenosis without a change in clinical status or cardiac exam • Re-evaluation (<1 yr) in patients with moderate or severe aortic stenosis, who will be subjected to increased hemodynamic demands (e.g. noncardiac surgery, pregnancy) • Re-evaluation of an asymptomatic patient with severe aortic stenosis 6-12 months without change in clinical status or cardiac exam • Re-evaluation after control of hypertension in low flow – low gradient severe aortic stenosis with preserved ejection fraction • In asymptomatic young adults, annual TTE for aortic stenosis with mean Doppler gradient > 30 mm Hg or peak instantaneous gradient >50 mm Hg, and every 2 years for patients with lesser gradients (Warnes 2008) • In asymptomatic patient with pulmonic stenosis, with peak instantaneous gradient < 30 mm Hg. follow up TTE at 5 year intervals (Warnes 2008) • In asymptomatic patient with pulmonic stenosis, with peak instantaneous gradient > 30 mm Hg, follow up TTE at 2-5 year intervals(Warnes 2008)
Native Valvular Regurgitation With TTE (aLancellotti 2013)
• Routine surveillance (≥1 yr) of moderate valvular regurgitation without change in clinical status or cardiac exam • Re-evaluation of asymptomatic patient (6-12 months) with severe aortic regurgitation with preserved ejection fraction and normal left ventricular size • Re-evaluation of asymptomatic patient (6-12 months) with severe mitral regurgitation
Prosthetic Valves With TTE
• Initial postoperative evaluation of prosthetic valve for establishment of baseline, typically 6 weeks to 3 months postoperative.
• Routine surveillance (≥3 y after valve implantation) of prosthetic valve if no known or suspected valve dysfunction
• Evaluation of prosthetic valve with suspected dysfunction or a change in clinical status or cardiac exam

• Re-evaluation of known prosthetic valve dysfunction when it would change management or guide therapy
• Evaluation prior to pregnancy in patients with a prosthetic valve and no echocardiography within the past year
Infective Endocarditis (Native or Prosthetic Valves) With TTE
• Initial evaluation of suspected infective endocarditis with positive blood cultures or a new murmur • Re-evaluation of infective endocarditis at high risk for progression or complication or with a change in clinical status or cardiac exam, or when findings might change management • Re-evaluation of prior TTE/TEE finding for interval change (e.g. resolution of vegetation after antibiotic therapy) when a change in therapy is anticipated or under consideration • Re-evaluation of patient with infective endocarditis at high risk of progression of complication (e.g., extensive infective tissue/large vegetation on initial echocardiogram, or staphylococcal, enterococcal, or fungal infections) in the absence of clinical change
Transcatheter Valvular Intervention

• Transcatheter Aortic Valve Replacement (TAVR), one of the following: (Otto 2017; Doherty 2017)
  • For pre-TAVR evaluation: Assessment of number cusps and degree of calcification
  • Post TAVR at 30 days (6 weeks to 3 months also acceptable) and annually
  • Post TAVR evaluation: Assessment of aortic regurgitation when there is suspicion of valvular dysfunction (<30 days)
  • Post TAVR evaluation: Assessment of stroke with suspicion of valve dysfunction or thrombus

• Percutaneous Mitral Valve Repair, one of the following: (Doherty 2017)
  o Determination of patient eligibility
  o Reassessment for degree of MR and left ventricular function (pre-discharge, at 1, 6, and 12 months, and then annually to 5 yr)

Additional Interventions or Noncardiac Procedures
• Guidance of and evaluation for percutaneous noncoronary cardiac procedures including but not limited to pericardiocentesis, septal ablation, right ventricular biopsy, cardiac valvular and structural interventions, radiofrequency ablation, or LVAD optimization or weaning (Wunderlich 2018; Porter 2015). • Periprocedural cardiac monitoring of noncardiac procedures posing substantial hemodynamic or ischemic risk, procedures requiring fluid resuscitation, etc., when it can assist management (Porter 2015).
Intracardiac and Extracardiac Structures
• Suspected cardiac mass (Saric 2016) • Suspected cardiovascular source of embolus (Saric 2016) • Suspected pericardial conditions • Re-evaluation of known pericardial effusion to guide management or therapy

Thoracic Aortic Disease

In the absence of recent computed tomography (CT) or cardiovascular magnetic resonance (CMR), which are preferred for imaging beyond the proximal ascending aorta (Hiratzka 2010; Hiratzka 2016; Erbel 2014; Schiller 2017; Wright a&b 2018; Woo a&b 2018; Svensson 2013' Bhave 2018)

(See table in Additional Information for top normal size of the thoracic aorta.)

- Screening first degree relatives of individuals with a history of thoracic aortic aneurysm (defined as ≥ 50% above normal) or dissection or an associated high risk mutation in common.
- Screening second degree relative of a patient with thoracic aortic aneurysm, when the first degree relative has aortic dilation, aneurysm, or dissection.
- Six month follow up after initial finding of a dilated thoracic aorta, for assessment of rate of change
- Annual follow up of enlarged thoracic aorta that is above top normal for age, gender, and size up to 4.4 cm
- Biannual (twice/yr) follow up of enlarged aortic root ≥ 4.5 cm or showing growth rate ≥ 0.5 cm/year
- Evaluation of the ascending aorta in the setting of a known or suspected connective tissue disease or genetic condition that predisposes to aortic aneurysm or dissection (e.g., Marfan syndrome, Ehlers Danlos or Loeys-Dietz syndromes,)
- At time of diagnosis of Marfan's syndrome and 6 months thereafter for growth rate assessment, followed by annual imaging, increased to biannual (twice yearly) if diameter >=4.5 or expanding >= 0.5 cm/yr
- Evaluation of aortic root in patient with Turner syndrome, along with aortic valve and coarctation evaluation, with normal results followed up at 5-10 years with repeat TTE, with abnormalities followed annually.
- Re-evaluation of known ascending aortic dilation or history of aortic dissection to establish a baseline rate of expansion (at 6 months from last assessment) or when the rate of expansion is excessive (repeat at 6 months)
- Re-evaluation of known ascending aortic dilation or history of aortic dissection with a change in clinical status or cardiac exam or when findings may alter management or therapy
- Re-evaluation (<1 y, generally twice a year) of the size and morphology of the aortic sinuses and ascending aorta in patients with a bicuspid AV and an ascending aortic diameter >4 cm with 1 of the following:
  1. Aortic diameter >4.5 cm
  2. Rapid rate of change in aortic diameter when an annual growth rate of ≥0.5 cm is suspected.
  3. Family history (first-degree relative) of aortic dissection
- Evaluation of a ruptured sinus of Valsalva aneurysm and resultant shunting
- Follow up post aortic medical treatment:
  - Acute dissection: Discharge, 1 month, 6 months, then annually
  - Chronic dissection: Discharge, years 1, 2, and 3.
- Follow up post either root repair or AVR plus ascending aortic root/arch repair: Discharge and annual

Hypertension, Heart Failure, or Cardiomyopathy
Hypertension
• Initial evaluation of suspected hypertensive heart disease
Heart Failure & LV Function (Nagueh 2016; Yancy 2013; Patel 2013)
• Initial evaluation of known or suspected heart failure (HF) (systolic or diastolic) based on symptoms, signs, or abnormal test results • Re-evaluation of known HF (systolic or diastolic) with a change in clinical status or cardiac exam without a clear precipitating change in medication or diet • Prior to cardiotoxic chemotherapy, and subsequently for monitoring and follow up. (See Cardio-Oncology section under the Additional Information section.) • Left ventricular function assessment at baseline prior to initiation of radiation to the anterior or left chest, at 5 years post initiation, and every 5 years thereafter (Lancellotti 2013b) • Assessment in patients with a history of prior myocardial infarction and unknown left ventricular function. • Re-evaluation of known HF (systolic or diastolic) when essential to guide therapy • Worsening in ventricular arrhythmias, including after implantable cardioverter defibrillator (ICD) placement (Patel 2013) • Unimproved heart failure symptoms in the first 6 months after cardiac resynchronization therapy (CRT initiation (Patel 2013)
Device Candidacy (Pacemaker, ICD, or CRT)
• Initial evaluation or re-evaluation after revascularization ($\geq$ 3 months or 90 days) and/or myocardial infarction ($\geq$ 40 days) and/or 3 months of optimal medical therapy to determine candidacy for device therapy and/or to determine optimal choice of device (Al-Khatib 2017) • Initial evaluation for CRT device optimization after implantation • Known implanted pacing device with symptoms possibly due to device complication or suboptimal pacing device settings
Ventricular Assist Devices (VADs) and Cardiac Transplantation (Stainback 2015)

• To determine candidacy for ventricular assist device
• Optimization of ventricular assist device settings and assessment of response post device
• Re-evaluation for signs/symptoms suggestive of ventricular assist device-related complications
• Assessment of alterations in valvular function post assist device, particularly aortic regurgitation.
• Assessment for myocardial recovery post assist device
• Monitoring for rejection in a cardiac transplant recipient
• **Follow up of transplanted heart patients' allograft with TTE:**
  o Every 3 months during the first year,
  o Every 6 months during the second year.
  o Alternatively, after each endomyocardial biopsy (Badano 2015)
• Cardiac structure and function evaluation in a potential heart donor

Cardiomyopathies (Yancy 2013)
• Initial evaluation of known or suspected cardiomyopathy (e.g., restrictive, infiltrative, dilated, hypertrophic, or genetic cardiomyopathy) • Re-evaluation of known cardiomyopathy with a change in clinical status or cardiac exam or to guide therapy and manage post transplantation or post ventricular assist device (VAD) patients • Screening evaluation for structure and function in first-degree relatives of a patient with an inherited cardiomyopathy • Assessment of peripartum cardiomyopathy at onset and 3 months, then at 6 month intervals for minimum two years, longer if required for surveillance during and after trial of weaning medication, with additional follow up of 2 years after weaning trial completed. Follow up as needed, including for intended or actual recurrent pregnancy. (Tsang 2018; Hilfiker-Kleiner 2015)
Adult Congenital Heart Disease (Warnes 2008; Baumgartner 2010)
• Initial evaluation of known or suspected adult congenital heart disease • Known adult congenital heart disease with a change in clinical status or cardiac exam • Re-evaluation to guide therapy in known adult congenital heart disease. • Evaluation of asymptomatic patients following repair of Atrial Septal Defect (ASD), Patent Foramen Ovale (PFO), Ventricular Septal Defect (VSD) or Patent Ductus Arteriosus (PDA), approvable within the first year following correction • Routine surveillance (≥1 yr) of adult congenital heart disease following incomplete or palliative repair with residual structural or hemodynamic abnormal, even without a change in clinical status or exam. • Asymptomatic, small ASD (<10 mm) shunt with normal right ventricular size, TTE follow up at 2 year intervals, more frequently for larger shunts with normal right ventricle • Follow up after device closure of shunts, TTE at 24 hours, 2 month, 6 months, 1 year intervals thereafter. • Asymptomatic small coronary arteriovenous fistula , TTE every 3 years • After arterial switch repair of d-transposition of the great arteries, TTE at least every 2 years • In congenitally corrected transposition of the great arteries, TTE every 1-2 years.

PEDIATRIC PATIENTS
(PATIENTS UNDER THE AGE OF 18)

Indications for an Initial Transthoracic Echocardiography (TTE)
(Campbell 2014)

- Hypertension.

- Palpitations, if one:
  - EKG is markedly abnormal
  - Family history at age <50 of either:
    - sudden cardiac arrest or
    - death, pacemaker, or ICD

- History or family history of cardiomyopathy

- Chest pain, if one of:
  - Exertional
  - Abnormal EKG
  - Family history with unexplained sudden death or cardiomyopathy
  - Associated features of the presentation are suspicious for cardiac origin (e.g. rheumatic fever, endocarditis)

- Syncope, if any one of:
  - History, exam, and/or EKG provide suspicion of structural heart disease
  - Exertional, especially mid exertional due to high correlation with structural heart disease and/or arrhythmic disorder
  - Unexplained post exertional
  - Family history at age < 50 of either one:
    - sudden cardiac death/arrest or
    - a pacemaker or ICD
  - There is a family history of cardiomyopathy

- Presyncope, when **all** apply:
  (Salerno 2018; Anderson 2016; Cote 2001; Shen 2017)
  - When recurrent and well documented
  - With good documentation that neither neutrally mediated syncope (NMS) nor orthostasis is the etiology
  - When structural or arrhythmia related structural heart disease is a suspected cause
  - **Without** prior echocardiographic diagnosis during the course of the current clinical status

- Signs and/or symptoms of heart failure, including, but not limited to any one of:
  - Respiratory distress
  - Poor peripheral pulses
  - Feeding difficulty
  - Decreased urine output
  - Edema
  - Hepatomegaly

- Abnormal physical findings, including any one of:
  - Clicks, snaps, or gallops
  - Fixed and/or abnormally split S2
  - Decreased pulses.
  - Central cyanosis without explanation.

- Arrhythmia, if one of:
  - Supraventricular tachycardia
  - Ventricular tachycardia
  - Frequent premature ventricular contractions (PVCs) (≥ 10% of beats/24 hours)

- Murmur
    - Pathologic sounding or harsh murmur, diastolic murmur, or continuous murmur, present in such a way as to have a reasonable belief that congenital heart disease might be present
    - An otherwise innocent murmur, but in the presence of signs, symptoms, or findings of cardiovascular disease

- Abnormal basic data, including any one of:
    - Clearly abnormal electrocardiogram (ECG)
    - Desaturation on pulse oximetry, with concern for cardiac cause
    - Abnormal cardiac structure on a chest x-ray

- Suspected pulmonary hypertension

- Patients with prosthetic valves

- Signs and symptoms of endocarditis, including either one of:
    - In the absence of positive blood cultures, including all patients with an indwelling catheter who present with unexplained fever
    - Positive blood cultures suggestive of infective endocarditis.

- Thromboembolic Related, either one:
    - Patients on anticoagulants, when required to evaluate for thrombus
    - Thromboembolic events or stroke (Saric 2016)

- Systemic hematologic diseases that are associated with cardiac findings, either one:
    - Sickle cell disease
    - HIV infection

- Oncologic Therapy, any one:
    - Cardiotoxic chemotherapy, before or following exposure
    - Radiation therapy to chest, before and long term follow up (Lancellotti 2013) (See Cardio-Oncology section under Additional Information section)

- Inflammatory & Autoimmune, any one:
    - Suspected Rheumatic Fever
    - Systemic lupus erythematosus
    - Takayasu Arteritis
    - Kawasaki Disease (Newburger 2004)

- Suspicion of Structural Disease, any one:
    - Premature birth where there is suspicion of a Patent Ductus Arteriosus.
    - Adopted children for whom there is a suspicion of congenital heart disease (e.g. HCM), based on physical or clinical findings when there is a lack of family history information.
    - Vascular Ring, based upon either one:
        - Difficulty breathing with stridor and eating solid foods that might suggest a vascular ring

        - Abnormal barium swallow or bronchoscopy suggesting a vascular ring
    - Ventricular pre-excitation with no clinical or Holter findings to suggest an arrhythmia, but with suspicion of Ebstein's anomaly, Tumors, HCM or clinical signs of heart failure

- Genetic & Syndrome Related, any one:
    - Genotype positive for cardiomyopathy, family history of hypertrophic cardiomyopathy, other heritable cardiomyopathy, genetic disorder at high risk for cardiovascular involvement, heritable pulmonary arterial hypertension
    - Syndromic patients with a known syndrome associated with congenital or acquired heart disease (Down's syndrome, Noonan's syndrome, 22Q deficiency syndrome, William's syndrome, Trisomy Thirteen, Trisomy Eighteen, Allagille syndrome, chromosomal abnormality associated with cardiovascular disease, abnormal viscera, or cardiac situs).
    - Known or suspected connective tissue diseases that are associated with congenital or acquired heart disease. (e.g. Marfan's, Loeys-Dietz)
    - Known or suspected muscular dystrophies associated with congenital heart disease.
    - Mitochondrial or metabolic storage disease (e.g. Fabry's disease)
    - Patients with a first degree relative who is known to have a genetic acquisition, such as cardiomyopathies (hypertrophic, dilated, arrhythmogenic right ventricular dysplasia, restrictive, left ventricular noncompaction).

- Maternal-Fetal Related, any one:
    - Maternal infection during pregnancy or delivery with potential fetal/neonatal cardiac sequelae
    - Maternal phenylketonuria
    - Suspected cardiovascular abnormality on fetal echocardiogram

- Previously normal echocardiogram with either one:
    - A change in cardiovascular status
    - A new family history suggestive of heritable heart disease

Indications for Follow-up Echocardiography in Pediatric Patients
(Davey 2004)

General Indications for Postoperative/Post-Procedure Pediatric Patients:
- Upon first outpatient visit, to establish the patient's new hemodynamic baseline, and assess for potential complications such as pericardial effusions, residual shunts, obstruction at the site of repair, patency of surgical shunts, etc.
- On subsequent visits as needed to monitor as medications are weaned or to evaluate need for further surgical intervention.

Specific Indications for Follow-Up Echocardiograms in Pediatric Patients:
- Congenital Heart Disease (CHD) with a change in clinical status.

- Kawasaki Disease, upon diagnosis, two weeks later and 4 to 6 weeks later. If any coronary abnormalities are present, echocardiograms may need to be more frequent as clinically indicated. (Newburger 2004)
- Valvular regurgitation that is more than mild in asymptomatic child may require annual echocardiogram to assess chamber size and progressive regurgitation.
- Valvular stenosis: (Peak Doppler [mm Hg]: Mild < 40, Moderate 40-60, Severe >60)
    - Pulmonic Stenosis (PS): (Peng 2018)
        - Mild to moderate PS in an infant up to 1-2 year: repeat at 2 weeks and 6 weeks to assess for increasing gradient as PVR drops.
        - Mild stenosis post infancy (6 weeks): every 6 months until age 2 years, and
            - If the gradient regresses to < 25 mm Hg, reduce follow up to every 5 years.
            - If the gradient remains 25-40 after one year, follow up in one year and then every 3 years, if stable
        - Moderate stenosis post infancy (6 weeks): every 1-2 years
        - Post intervention for severe: every year for two years, then every 3-5 years, if stable; also depends on result of valvuloplasty
    - Aortic Stenosis (AS): (Aortic regurgitation rarely alone, usually with aortic stenosis) (Brown 2018)
      (Mean Gradients [mm Hg] mild < 25, moderate 25-40, severe > 40)
        - Mild AS in an infant: every 6 months, or more depending on the patient's clinical status and rate of progression.
        - Moderate AS in an infant: every 1-3 months to assess for progression and indication for valvuloplasty.
        - Mild in an asymptomatic child: every 1-2 years to assess for progression of stenosis
        - Moderate AS in an asymptomatic child: at least every 6-12 months to assess for progressive stenosis, left ventricular hypertrophy, post-stenotic dilation.
        - In asymptomatic adolescents, annual TTE for aortic stenosis with mean Doppler gradient > 30 mm Hg or peak instantaneous gradient >50 mm Hg, and every 2 years for patients with lesser gradients. (Warnes 2008)
    - Aortic valve prosthesis (Brown 2018)
        - Mechanical: every 6-12 months
        - Bioprosthetic: every 3-6 months
    - Mitral Stenosis (MS):
        - MS from Rheumatic Heart Disease on no meds with no symptoms may require an annual echocardiogram.
        - MS with CHF on medications may require an echocardiogram every three to 6 months.
    - Tricuspid Stenosis (TS):
        - A rare indication that would be based on the patient's course of treatment and clinical symptoms.
- Shunt lesions:
    - Ventricular Septal Defect (VSD): (Fulton 2018)
      (Pulmonary to systemic shunt ratio: small < 1.5, moderate 1.5-2.0, large > 2.0) (Oakley 2008)

        - Infants with VSD: repeat echocardiogram at 2 weeks and 6 weeks to assess for increasing shunt as the PVR drops.
        - Small VSD: annual echocardiogram to assess for associated lesions depending on location of defect, i.e. aortic regurgitation, development of DCRV (double chambered right ventricle); after 6 months, if the murmur is gone repeat echo is not necessary, if otherwise stable.
        - Moderate to large VSD, asymptomatic: Close follow up in response to patient's clinical status, to assess for LV dilation, mitral regurgitation, and associated lesions; if after one year, there is no pulmonary hypertension or left ventricular dilation, echo can be performed every 2 years, if stable.
    - Atrial Septal Defect (ASD): (Vick 2018)
        - Moderate to large secundum ASD (≥ 3 mm or shunt ≥ 1.5:1) and all primum, sinus venosus, and coronary sinus ASDs, at 6 months intervals to assess for progressive RV dilation, tricuspid regurgitation.
        - Small secundum (< 3mm and shunt < 1.5: 1) ASD: every 1-3 years, depending on age of patient.

NOT INDICATED unless there is treating physician input during a peer-to-peer discussion that supports the need for an echocardiogram.

- Chest pain that changes with inspiration.
- Clear Orthostatic Hypotension.
- Chest pain that increases upon palpation.
- High cholesterol/triglycerides in children who have no other indication for an echocardiogram.
- Isolated prolonged QT syndrome with no clinical or Holter evidence of an arrhythmia or other physical findings.

NOT INDICATED:

- Attention Deficit Disorder with no other relevant findings.
- A sports physical with normal history, physical and ECG.
- Parental request as the sole reason for an echocardiogram.
- All patients with a 1st degree relative with an inherited form of cardiomyopathy where the patient has been definitively excluded by genetic testing.

ADDITIONAL INFORMATION

I. Imaging Surveillance for Cardiotoxic Chemotherapy

(Plana 2014; Zamorano 2016; Maleszewski 2018; Herrmann 2014)

TTE is the method of choice for the evaluation of patients before, during, and after cancer therapy. Ideally accuracy prefers that 3D and global longitudinal strain (GLS) are part of the exam, and serum troponin (Tn) should also be measured. However, GLS and Tn might not have been performed, in which case determinations might need to be made with LVEF only. *Serum troponin (Tn) and GLS abnormities constitute an abnormal assessment of LV function, because their abnormalities frequently herald an imminent fall in LVEF.* (Plana 2014; Zamorano 2016)

CMR is recommended when TTE has been unreliable and/or candidacy for cardiotoxic chemotherapy based upon LVEF is questionable (Plana 2014) (MUGA can also be considered when TTE is inadequate and CMR is not available).

MUGA is accurate and reproducible, but lacks information about pericardium and valves, incurs repeated radiation exposure, and is inaccurate during an irregular cardiac rhythm (Plana 2014).

Surveillance guidelines are somewhat complex, possibly beyond the scope of this guideline, especially in patients with additional risk factors for LV dysfunction (Herrmann 2014). As with all guidelines, adequate information for complex decisions might be impractical to acquire. However, if the reader requires more rigorous recommendations, they are summarized concisely in the table below. **Necessity determinations might not require strict adherence to this table at this time, but it is here to serve as a helpful reference for the reader, if desired.**

TTE Surveillance Strategy for Cardiotoxic Chemotherapy (Optional Information)
(Plana 2014; Herrmann 2014; Zamorano 2016; Maleszewski 2018)

Suspected/Detected LV Status at Baseline, During, or After Completion of Therapy (LVEF is minimum information, GLS and Tn can reveal early LV dysfunction prior to LVEF)	**Type I** **Anthracyclines: Doxorubicin, Epirubicin, Idarubicin Mitoxantrone** (Asnani 2018)	**Type II** **Trastuzumab, Labatinib, Pertuzumab, Sorafenib, Sunitinib, Bevacizumab, Bortezomib ****
Normal: EF is ≥ 55%, troponin is negative, *and* global longitudinal strain (GLS) > lower limit of normal*	**Normal assessment:** Assess after a cumulative dose > 200mg/M^2 (or its anthracycline equivalent) *and* prior to each additional 50 mg/M^2, *and* at completion of therapy, and 6 months later, *and* for cumulative dose > 300 mg/M^2 include assessment at 1 year and at 5 years post completion of therapy. (Zamorano 2016)	**Normal assessment:** Assess every 3 months during therapy *and* at 6 months post completion of therapy
Abnormal: any *one* of: o GLS reduced ≥ 10-15% below normal (about 20 is normal*, labs vary) o Troponin positive o LVEF started < 55% o During therapy LVEF drops below 55% AND ≥ 5 points for a symptomatic/≥10 points for an asymptomatic patient. (Maleszewski 2018)	**Abnormal assessment:** Assess after every cycle, *and* re-assess for verification 2-3 weeks later if a drop in LV function has been detected/suspected; assess 6 months post completion of therapy, followed by re-assessment every 6 months until stable, *and* for cumulative dose > 300 mg/M^2 include assessment at 1 year *and* 5 years post completion of therapy. (Zamorano 2016)	**Abnormal assessment:** Assess after every cycle, *and* re-assess for verification 2-3 weeks later if a drop in LV function has been detected /suspected; assess 6 months post completion of therapy, *and* if still not stable re-assess every 6 months until stable.

* GLS of (negative) 20 is generally normal, but individual labs vary. (Collier 2017)
** Imatinib, rarely cardiotoxic, does not require surveillance of LV function. (Floyd 2018)

II. Aortic Root Disease

(Hiratzka 2010; Erbel 2014; Schiller 2017; Wright a&b 2018; Woo a&b 2018; Svensson 2013; Doherty 2017; Bhave 2018)

Indications for aortic root disease in this document are further explained in the section below:

- In asymptomatic stable patients with aortic dilation:

1. All 3 modalities of imaging, computed tomography (CT), magnetic resonance imaging (MRI), Echocardiography (TTE and TEE) appear to be reasonable alternatives for the diagnosis and surveillance of aortic pathology with 3 caveats:
    - TTE accuracy is limited to the aortic valve, aortic root, and proximal ascending aorta, so that conditions requiring evaluation of more distal portions are better imaged with CT or MRI. TEE's invasive nature and weak visualization of the distal ascending aorta, proximal arch, and abdominal aorta make it suboptimal as well. TTE might be satisfactory for surveillance in pathology with greatest prominence localized to the proximal ascending aorta (in bicuspid aortic valve disease or when prior CT or MRI showed the most dilated portion of the aorta to be visible on TTE), until its dimensions approach surgical indications, at which time more precise or comprehensive imaging with CT and MRI might be more appropriate.
    - MRI is recommended for Loeys Dietz, Ehlers-Danlos, and certain other noted genetic mutations, wherein surgical intervention is recommended at 4.2 cm.
    - While still usable for degenerative aortic dilation, echocardiography appears less favorable than CT or MRI for this indication.
    - CT and MRI were recommended for postoperative evaluation and periodic follow up. Echocardiography was not a noted recommendation for this category.

2. The flow diagram from the 2010 ACC Thoracic Aortic Disease Guideline gives reasonable recommendations for surveillance of degenerative aortic root disease, with annual imaging for enlargement above normal up to 4.4 cm, biannual for 4.5-5.4 or more cm (surgical intervention notwithstanding). See Table below for age, gender, and body size determined upper limits of normal for the thoracic aorta, ascending and descending:

Aortic diameters: Upper limits of normal[a]

Age (years)	BSA (m^2)	Ascending aorta (mm)		Descending aorta (mm)	
		Women (n = 1,147)	Men (n = 1,805)	Women (n = 736)	Men (n = 1,195)
< 45	< 1.70	33.8	33.0	23.0	NA
	1.70–1.89	34.4	36.3	24.6	26.6
	1.90–2.09	35.0	36.3	22.7	26.7
	> 2.1	NA	38.3	NA	28.3
45–54	< 1.70	35.2	38.6	24.3	24.2
	1.70–1.89	37.2	38.1	25.4	27.5
	1.90–2.09	38.9	39.7	27.2	29.2
	> 2.1	40.6	40.6	28.3	29.6
55–64	< 1.70	36.9	36.3	25.9	26.1
	1.70–1.89	37.0	39.7	27.1	28.6
	1.90–2.09	39.0	41.2	27.8	29.9
	> 2.1	42.0	43.1	31.7	31.6
≥ 65	< 1.70	37.5	38.5	27.0	NA
	1.70–1.89	39.2	41.0	27.4	32.4
	1.90–2.09	42.7	42.2	29.0	31.0
	> 2.1	NA	42.4	29.8	32.5

[a]Upper limits of normal are 2 standard deviations above the mean. Not calculated if there were fewer than 6 patients in a group.
BSA = body surface area; NA = not available

(Table from Wolak 2008, as adapted by Cikach 2018)
An aneurysm is defined as ≥ 50% greater than top normal. (Cikach 2018; Hiratzka 2010)

It would be reasonable to allow echocardiography as a less favorable alternative to CT and MRI, based upon the judgement of the ordering physician and local expertise with imaging (The definition of a thoracic aortic aneurysm is dilation of at least 50% above the normal) (Cikach 2018; Hiratzka 2010).

3. An echocardiogram is recommended at the time of diagnosis of Marfan syndrome to determine the aortic root and ascending aortic diameters and 6 months thereafter to determine the rate of enlargement of the aorta. Subsequently, patients with Marfan's require annual imaging, with increase to biannual imaging at a diameter of 4.5 cm or when > 0.5 cm/yr expansion has been noted.

4. Patients with bicuspid aortic valve and aortic dilation over 4.0 cm require annual imaging. This would increase to biannual imaging in the event of any one of the additional conditions: diameter > 4.5 cm, rapid rate of change 0.5 cm/yr, or a family history of a first degree relative with aortic dissection.

5. Patients with Loeys-Dietz syndrome or a confirmed genetic mutation known to predispose to aortic aneurysms and aortic dissections (*TGFBR1, TGFBR2, FBN1, ACTA2,* or *MYH11*) should undergo **complete aortic imaging** at initial diagnosis and 6 months thereafter to establish if enlargement is occurring. MRI is recommended in this setting.

6. Patients with Loeys-Dietz syndrome should have yearly **magnetic resonance imaging** from the cerebrovascular circulation to the pelvis.

7. Patients with Turner syndrome should undergo imaging of the heart and aorta for evidence of bicuspid aortic valve, coarctation of the aorta, or dilatation of the ascending thoracic aorta. If initial imaging is normal and there are no risk factors for aortic dissection, repeat imaging should be performed every 5 to 10 years or if otherwise clinically indicated. If abnormalities exist, annual imaging or otherwise appropriate follow-up imaging should be done.

8. Computed tomographic imaging or magnetic resonance imaging of the thoracic aorta is reasonable after a Type A or B aortic dissection or after prophylactic repair of the aortic root/ascending aorta.

9. Echocardiography is the primary modality for evaluation of the sinus of Valsalva aneurysms and associated shunting secondary to rupture (Schiller 2018).

10. Computed tomographic imaging or magnetic resonance imaging of the aorta is reasonable at 1, 3, 6, and 12 months post un-operated dissection and, if stable, annually thereafter so that any threatening enlargement requiring surgery/intervention can be detected in a timely fashion.

11. Postoperative surveillance recommendations are taken from the 2010 ACC Thoracic Aortic Disease Guideline: See Table below (Hiratzka 2010)

Table 17. Suggested Follow-Up of Aortic Pathologies After Repair or Treatment

Pathology	Interval	Study
Acute dissection	Before discharge, 1 mo, 6 mo, yearly	CT or MR, chest plus abdomen TTE
Chronic dissection	Before discharge, 1 y, 2 to 3 y	CT or MR, chest plus abdomen TTE
Aortic root repair	Before discharge, yearly	TTE
AVR plus ascending	Before discharge, yearly	TTE
Aortic arch	Before discharge, 1 y, 2 to 3 y	CT or MR, chest plus abdomen
Thoracic aortic stent	Before discharge, 1 mo, 2 mo, 6 mo, yearly Or 30 days*	CXR, CT, chest plus abdomen
Acute IMH/PAU	Before discharge, 1 mo, 3 mo, 6 mo, yearly	CT or MR, chest plus abdomen

*US Food and Drug Administration stent graft studies usually required before discharge or at 30-day CT scan to detect endovascular leaks. If there is concern about a leak, a predischarge study is recommended; however, the risk of renal injury should be borne in mind. All patients should be receiving beta blockers after surgery or medically managed aortic dissection, if tolerated. Adapted from Erbel et al (539).

AVR indicates aortic valve replacement; CT, computed tomographic imaging; CXR, chest x-ray; IMH, intramural hematoma; MR, magnetic resonance imaging; PAU, penetrating atherosclerotic ulcer; and TTE, transthoracic echocardiography.

(Table from Hiratzka 2010)

III. General Information on TTE

(Douglas 2011; Campbell 2014; Nishimura 2014; Doherty 2017)

Frequency of Echocardiography Studies

- Judgement required, based upon:
  - Stability or change in patient symptoms, exam, lab, and/or X ray data
  - Stability of underlying condition being followed
  - Likelihood of repeat test affecting management
  - Specifics for cardio-oncology, valvular disease, etc.

Examples of non-approvable repeat imaging:

- For same imaging test less than 52 weeks apart unless specific guideline criteria states otherwise.

- For different imaging tests of same anatomical structure but different imaging type less than six (6) weeks ago (i.e. CT, MRI and currently requesting echocardiogram) unless specific guideline criteria states otherwise, and/or there is approval following high level review.

- Additional images from same type of study (e.g. due to poor quality).

Pediatric Post-Operative Patients

Congenital heart disease, which requires surgical palliation, is, by its very nature, quite varied. No written consensus criteria currently exists for monitoring post-operative patients, but rather is based upon the clinical experience and training of the Pediatric Cardiologists caring for the patient. Criteria for performing an echocardiogram in the out-patient setting will vary greatly based upon whether the patient has a complex lesion, which must be repaired in stages, had post-operative complications, or is on medications which will be weaned over the ensuing weeks.

Murmurs

A harsh murmur, diastolic murmur, or continuous murmur would be an indication for an echocardiogram. Soft systolic murmurs and vibratory murmurs in general would not be indications for an echocardiogram. There is an important caveat in regards to age. Existent literature suggests that young children particularly under the age of three can have what appear to be unremarkable murmurs that result in organic heart disease even when examined by experts. Great leeway should therefore be given when echocardiograms are performed under the age of 3 years.

TTE Accuracy

In general, transthoracic echocardiography (TTE) is adequate for diagnosing infective endocarditis (IE) and for identifying vegetations when image quality is good. Contemporary TTE has improved the diagnostic accuracy of IE with enhanced image quality; it may reduce the need for TEE. However, accuracy may be reduced because of technical difficulties like obesity, chronic obstructive pulmonary disease, chest-wall deformities etc. Furthermore, the higher resolution of TEE can provided superior visualization of smaller vegetations.

TTE versus TEE

Specific situations where transesophageal echocardiography (TEE) is preferred over TTE and may be an appropriate initial study for evaluation of prosthetic device, suspected peri-annular complications, children with complex congenital cardiac lesions, selected patients with Staphylococcus aureus bacteremia, etc. Visualization of left atrial thrombus is far superior with TEE, which is the recommended strategy.

Abbreviations

ASD	atrial septal defect
CABG	coronary artery bypass grafting surgery
CAD	coronary artery disease
CMR	cardiovascular magnetic resonance
CRT	cardiac resynchronization therapy
CT	computed tomography
ECG	electrocardiogram
GLS	global longitudinal strain (measure of left ventricular function)
HCM	hypertrophic cardiomyopathy
HF	heart failure
ICD	implantable cardioverter-defibrillator
LV	left ventricular
LVEF	left ventricular ejection fraction
MI	myocardial infarction
PDA	patent ductus arteriosus
PFO	patent foramen ovale
SVT	supraventricular tachycardia
TAVR	transcatheter aortic valve replacement
TEE	transesophageal echocardiogram
TIA	transient ischemic attack
Tn	troponin
TTE	transthoracic echocardiogram
VPC	ventricular premature contraction
VSD	ventricular septal defect
VT	ventricular tachycardia

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