1. How does echocardiography work?
Echocardiography uses transthoracic and transesophageal probes that emit ultrasound directed at cardiac structures. Returning ultrasound signals are received by the probe, and the computer in the ultrasound machine uses algorithms to reconstruct images of the heart. The time it takes for the ultrasound to return to the probe determines the depth of the structures relative to the probe because the speed of sound in soft tissue is relatively constant (1540 msec). The amplitude (intensity) of the returning signal determines the density and size of the structures with which the ultrasound comes in contact.

The probes also perform Doppler, which measures the frequency shift of the returning ultrasound signal to determine the speed and direction of moving blood through heart structures (e.g., through the aortic valve) or in the myocardium itself (tissue Doppler imaging). Appropriateness criteria for obtaining an echocardiogram are given in Box 6-1.

2. What is the difference between echocardiography and Doppler?
Echocardiography usually refers to two-dimensional (2D) ultrasound interrogation of the heart in which the brightness mode is utilized to image cardiac structures based on their density and location relative to the chest wall (Fig. 6-1). Two-dimensional echocardiography is particularly useful for identifying cardiac anatomy and morphology, such as identifying a pericardial effusion, left ventricular aneurysm, or cardiac mass.

Doppler refers to interrogation of the movement of blood in and around the heart, based on the shift in frequency (Doppler shift) that ultrasound undergoes when it comes in contact with a moving object (usually red blood cells). Doppler has three modes:

- Pulsed Doppler (Fig. 6-2, A), which can localize the site of flow acceleration but is prone to aliasing
- Continuous-wave Doppler (Fig. 6-2, B), which cannot localize the level of flow acceleration but can identify very high velocities without aliasing
- Color Doppler (Fig. 6-3), which utilizes different colors (usually red and blue) to identify flow toward and away from the transducer, respectively, and identify flow acceleration qualitatively by showing a mix of color to represent high velocity or aliased flow

Doppler is particularly useful for assessing the hemodynamic significance of cardiac structural disease, such as the severity of aortic stenosis (see Fig. 6-2), degree of mitral regurgitation (see Fig. 6-3), flow velocity across a ventricular septal defect, or severity of pulmonary hypertension.

The great majority of echocardiograms are ordered as echocardiography with Doppler to answer cardiac morphologic and hemodynamic questions in one study (e.g., a mitral stenosis murmur); 2D echo to identify the restricted, thickened, and calcified mitral valve (see Fig. 6-1); and Doppler to analyze its severity based on transvalvular flow velocities and gradients.

3. How is systolic function assessed using echocardiography?
The most commonly used measurement of left ventricular (LV) systolic function is left ventricular ejection fraction (LVEF), which is defined by:

\[
\text{LVEF} = \frac{\text{End-diastolic volume} - \text{End-systolic volume}}{\text{End-diastolic volume}}
\]
Simpson’s method (method of discs), in which the LV endocardial border of multiple slices of the left ventricle is traced in systole and diastole and the end-diastolic and end-systolic volumes are computed from these tracings, is one of the most common methods of calculating LVEF.

The Teicholz method, in which the shortening fraction:

\[
\frac{\text{LV end-diastolic dimension} - \text{LV end-systolic dimension}}{\text{LV end-diastolic dimension}} \times 1.7
\]

is multiplied by 1.7, can also be used to estimate LVEF, although this method is inaccurate in patients with regional wall motion abnormalities.

Visual estimation of LVEF by expert echocardiography readers is also commonly used.

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**BOX 6-1. APPROPRIATENESS CRITERIA FOR ECHOCARDIOGRAPHY**

**Appropriate indications include, but are not limited to:**
- Symptoms possibly related to cardiac etiology, such as dyspnea, shortness of breath, lightheadedness, syncope, cerebrovascular events.
- Initial evaluation of left-sided ventricular function after acute myocardial infarction.
- Evaluation of cardiac murmur in suspected valve disease.
- Sustained ventricular tachycardia or supraventricular tachycardia.
- Evaluation of suspected pulmonary artery hypertension.
- Evaluation of acute chest pain with nondiagnostic laboratory markers and electrocardiogram.
- Evaluation of known native or prosthetic valve disease in a patient with change of clinical status.

**Uncertain indications for echocardiography:**
- Cardiovascular source of embolic event in a patient who has normal transthoracic echocardiogram (TTE) and electrocardiogram findings and no history of atrial fibrillation or flutter.

**Inappropriate indications for echocardiography:**
- Routine monitoring of known conditions, such as heart failure, mild valvular disease, hypertensive cardiomyopathy, repair of congenital heart disease, or monitoring of an artificial valve, when the patient is clinically stable.
- Echocardiography is also not the test of choice in the initial evaluation for pulmonary embolus and should not be routinely used to screen asymptomatic hypertensive patients for heart disease.

**Appropriate indications for transesophageal echocardiography (TEE) as the initial test instead of TTE:**
- Evaluation of suspected aortic pathology including dissection.
- Guidance during percutaneous cardiac procedures including ablation and mitral valvuloplasty.
- To determine the mechanism of regurgitation and suitability of valve repair.
- Diagnose or manage endocarditis in patients with moderate-high probability of endocarditis.
- Persistent fever in a patient with an intracardiac device.
- TEE is not appropriate in evaluation for a left atrial thrombus in the setting of atrial fibrillation when it has already been decided to treat the patient with anticoagulant drugs.

Increasingly, state-of-the-art full volume acquisition using three-dimensional echocardiography can be used to provide accurate LVEF.

- Systolic dysfunction in the presence of preserved LVEF (more than 50%)—such as in patients with hypertrophic hearts, ischemic heart disease, or infiltrative cardiomyopathies—can be identified by depressed systolic tissue Doppler velocities.

4. **What is an echocardiographic diastolic assessment? What information can it provide?**

A diastolic assessment does two things: identifies LV relaxation and estimates LV filling pressures. LV relaxation is described as the time it takes for the LV to relax in diastole to accept blood from the left atrium (LA) through an open mitral valve. A normal heart is very elastic *(lussitropic)* and readily accepts blood during LV filling. When relaxation is impaired, the LV cannot easily accept increased volume, and this increased LV preload results in increases in LA pressure, which in turn results in pulmonary edema.
Figure 6-2. A, shows pulsed Doppler in the left ventricular outflow tract in a patient with aortic stenosis. The peak velocity of the spectral tracing (arrow) is 1.2 msec, indicating normal flow velocity proximal to the aortic valve. B, shows continuous Doppler across the aortic valve revealing a peak velocity of 4.5 msec (dashed arrow). Therefore, the blood flow velocity nearly quadrupled across the stenotic aortic valve, consistent with severe aortic stenosis.
LV relaxation is usually best determined using tissue Doppler imaging, which assesses early diastolic filling velocity (Ea) of the LV myocardium. Normal hearts have Ea 10 cm/sec or greater; impaired relaxation is present when Ea is less than 10 cm/sec.

An indicator of LV preload is peak transmitral early diastolic filling velocity (E), which measures the velocity of blood flow across the mitral valve. An estimate of the LV filling pressure can be made using the ratio of blood flow velocity across the mitral valve (E) to the velocity of myocardial tissue during early diastole. A high ratio (e.g., E/Ea ≥ 15) indicates elevated LV filling pressure (LA pressure ≥ 15 mm Hg); a lower ratio (e.g., E/Ea ≤ 10) indicates normal LV filling pressure (LA pressure < 15 mm Hg).

5. **How can echocardiography with Doppler be used to answer cardiac hemodynamic questions?**

- Stroke volume and cardiac output can be obtained with measurements of the LV outflow tract and time-velocity integral (TVI) of blood through the LV outflow tract.
- Doppler evaluation of right ventricular outflow tract diameter and TVI similarly allow measurement of right ventricular output.
- Tricuspid regurgitation peak gradient can be added to estimate of right atrial pressure to in turn estimate pulmonary artery systolic pressure.
Mitral inflow velocities, deceleration time, pulmonary venous parameters, and tissue Doppler imaging of the mitral annulus can give accurate assessment of LV diastolic function, including LV filling pressures.

Measurement of TVI and valve annular diameters can be used to assess intracardiac shunts (Qp/Qs) and regurgitant flow volumes.

Pressure gradients across native and prosthetic valves and across cardiac shunts can be used to assess hemodynamic severity of valve stenosis, regurgitation, or shunt severity, respectively.

Respiratory variation in valvular flow can aid in the diagnosis of cardiac tamponade or constrictive pericarditis.

6. **How is echocardiography used to evaluate valvular disease?**
   - Two-dimensional echocardiography can provide accurate visualization of valve structure to assess morphologic abnormalities (calcification, prolapse, flail, rheumatic disease, endocarditis). See Fig. 6-1, demonstrating the restricted movement of the mitral valve in a patient with mitral stenosis.
   - Color Doppler can provide semiquantitative assessment of the degree of valve regurgitation (mild, moderate, severe) in any position (aortic, mitral, pulmonic, tricuspid).
   - Pulsed Doppler can help pinpoint the location of a valvular abnormality (e.g., subaortic versus aortic versus supraaortic stenosis). Pulsed Doppler can also be used to quantify regurgitant volumes and fractions using the continuity equation.
   - Continuous-wave Doppler is useful for determining the hemodynamic severity of stenotic lesions, such as aortic or mitral stenosis.

7. **How can echocardiography help diagnose and manage patients with suspected pericardial disease?**
   - Echocardiography can diagnose pericardial effusions (Fig. 6-4) as fluid in the pericardial space readily transmits ultrasound (appears black on echo).

![Figure 6-4. Parasternal long axis view showing a large pericardial effusion (PE) surrounding the heart. LV, Left ventricle; RV, right ventricle. (From Kabbani SS, LeWinter M: Cardiac constriction and restriction. In Crawford MH, DiMarco JP: Cardiology, St. Louis, Mosby, 2001.](image-url)
Two-dimensional echocardiography and Doppler are pivotal in determining the hemodynamic impact of pericardial fluid; that is, whether the patient has elevated intrapericardial pressure or frank cardiac tamponade.

The following are indicators of elevated intrapericardial pressure in the setting of pericardial effusion:
- Diastolic indentation or collapse of the right ventricle (RV)
- Compression of the right atrium (RA) for more than one third of the cardiac cycle
- Lack of inferior vena cava (IVC) collapsability with deep inspiration
- 25% or greater variation in mitral or aortic Doppler flows
- 50% or greater variation of tricuspid or pulmonic valves flows with inspiration

Echocardiographic signs of constrictive pericarditis include: thickened or calcified pericardium, diastolic bounce of the interventricular septum, restrictive mitral filling pattern with 25% or greater respiratory variation in peak velocities, and lack of inspiratory collapsibility of the inferior vena cava.

Echocardiography is additionally useful for guiding precutaneous needle pericardiocentesis by identifying the transthoracic or subcostal window with the largest fluid cushion, monitoring decrease of fluid during pericardiocentesis, and in follow-up studies, assessing for reaccumulation of fluid.

8. What is the role of echocardiography in patients with ischemic stroke?
The following are echocardiographic findings that may be associated with a cardiac embolic cause in patients with stroke:
- Depressed LV ejection fraction, generally less than 40%
- Left ventricular or left atrial clot (Fig. 6-5)
- Intracardiac mass such as tumor or endocarditis

![Figure 6-5. Transesophageal echocardiography showing a left atrial thrombus (arrow). Ao, Aortic valve; LA, left atrium; LV, left ventricle.](image-url)
- Mitral stenosis (especially with a history of atrial fibrillation)
- Prosthetic valve in the mitral or aortic position
- Significant atherosclerotic disease in the aortic root, ascending aorta, or aortic arch
- Saline contrast study indicating a significant right to left intracardiac shunt, such as atrial septal defect

Note: A normal transthoracic echocardiogram in a patient without atrial fibrillation generally excludes a cardiac embolic source of clot and generally obviates the need for transesophageal echocardiography (TEE).

9. What are the echocardiographic findings in hypertrophic cardiomyopathy (HCM)?
- Septal, concentric, or apical hypertrophy (walls greater than 1.5 cm in diameter)
- The presence of systolic anterior motion (SAM) of the mitral valve in some cases of obstructive hypertrophic cardiomyopathy
- Dynamic left ventricular outflow tract (LVOT) gradients caused by SAM, midcavitary obliteration, or apical obliteration

10. What are the common indications for transesophageal echocardiography?
- Significant clinical suspicion of endocarditis in patients with suboptimal transthoracic windows
- Significant clinical suspicion of endocarditis in patients with prosthetic heart valve
- Suspected aortic dissection (Fig. 6-6)
- Suspected atrial septal defect (ASD) or patent foramen ovale in patients with cryptogenic embolic stroke

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**Figure 6-6.** Transesophageal echocardiography revealing dissection of the descending thoracic aorta. The true aortic lumen (true) is seen separated from the false lumen (false) by the dissection.
Embolic stroke with nondiagnostic transthoracic echo
Endocarditis with suspected valvular complications (abscess, fistula, pseudoaneurysm)
Evaluation of the mitral valve in cases of possible surgical mitral valve
Intracardiac shunt in which the location is not well seen on transthoracic echocardiography
Assessment of the left atria and left atrial appendage for the presence of thrombus (clot) (see Fig. 6-5) prior to planned cardioversion

11. What is contrast echocardiography?
Contrast echocardiography involves injection of either saline contrast or synthetic microbubbles (perflutren bubbles) into a systemic vein, then imaging the heart using ultrasound. Saline contrast, because of its relatively large size, does not cross the pulmonary capillary bed, and it therefore is confined to the right heart. Therefore, rapid appearance of saline contrast in the left heart indicates an intracardiac shunt.

Because synthetic microbubbles are smaller than saline bubbles, they cross the pulmonary capillaries and are used to image left heart structures. Most commonly, synthetic microbubbles are used to achieve better endocardial border definition in patients with suboptimal echocardiographic windows. Contrast is also used to better visualize structures such as possible LV clots or other masses.

Both synthetic and saline contrast can be used to augment Doppler signals, for example, in patients with pulmonary hypertension in whom a tricuspid regurgitation jet is needed to estimate pulmonary artery pressure.

12. What is stress echocardiography?
Stress echocardiography involves imaging the heart first at rest and subsequently during either exercise (treadmill or bike) or pharmacologic (usually dobutamine) stress to identify left ventricular (LV) wall motion abnormalities resulting from the presence of flow-limiting coronary artery disease.

Other uses of stress echocardiography include:
- Assessment of mitral or aortic valve disease in patients who have moderate disease at rest but significant symptoms with exercise
- Assessment of patients with suspected exercise-induced diastolic dysfunction
- Assessment of viability in patients with depressed ejection fractions. Improvement in left ventricular function with infusion of low-dose dobutamine (<10 μg/kg/min) suggests viable myocardium.
- Distinguishing between true aortic stenosis and pseudo aortic stenosis in patients with mild-moderate aortic stenosis at rest and depressed ejection fraction with low cardiac output

BIBLIOGRAPHY, SUGGESTED READINGS, AND WEBSITES


