The development of three-dimensional echocardiographic imaging techniques offers great promise for more accurate measurements of chamber volumes and mass, as well as the assessment of geometrically complex anatomy and valvular lesions. Video 4-1 shows a three-dimensional image.

Doppler echocardiography allows assessment of the direction and velocity of blood flow in the heart and great vessels. When ultrasound waves encounter moving red blood cells, the energy reflected to the transducer is altered. The magnitude of this change (i.e., Doppler shift) is represented as velocity on the echocardiographic display and can be used to determine whether the blood flow is normal or abnormal (Fig. 4-10). The velocity of a particular jet of blood can be converted to pressure using the modified Bernoulli equation ($\Delta P \cong 4v^2$). This process allows assessment of pressure gradients across valves or between chambers. Color Doppler imaging allows visualization of blood flow through the heart by assigning a color to the red blood cells based on their velocity and direction (Fig. 4-11, Video 4-2). By convention, blood moving away from the transducer is represented in shades of blue, and blood moving toward the transducer is represented in red. Color Doppler imaging is particularly useful in identifying valvular insufficiency and abnormal shunt flow between chambers. The use of Doppler techniques to record myocardial velocities or strain rates has provided insights into myocardial function and hemodynamics.

Two-dimensional echocardiography and Doppler echocardiography are often used in conjunction with exercise or pharmacologic stress testing. Although sensitivity and specificity values vary among studies, the sensitivity of stress echocardiography is apparently slightly lower and the specificity slightly higher compared with myocardial perfusion imaging using nuclear tracers. The estimated cost-effectiveness of stress echocardiography is significantly better than nuclear perfusion imaging because of the lower cost.

The development of ultrasound contrast agents composed of microbubbles that are small enough to transit through the pulmonary circulation has greatly improved the ability to use ultrasound to image obese patients, patients with lung disease, and those with otherwise difficult acoustic windows (Fig. 4-12). Video 4-3 shows a dynamic contrast echocardiographic image.

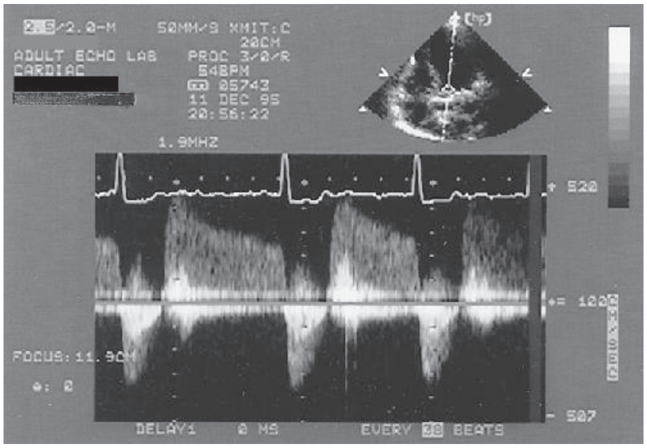

FIGURE 4-10 Doppler tracing in a patient with aortic stenosis and regurgitation. The velocity of systolic flow is related to the severity of obstruction.

These agents are being developed for molecular imaging by complexing the bubbles to compounds that can selectively bind to the target site of interest (i.e., clots, neovessels).

Transesophageal echocardiography (TEE) allows two-dimensional and Doppler imaging of the heart through the esophagus by having the patient swallow a gastroscope mounted with an ultrasound crystal in its tip. Given the proximity of the esophagus to the heart, high-resolution images can be obtained, especially of the left atrium, mitral valve apparatus, and aorta. TEE is particularly useful in diagnosing aortic dissection, endocarditis, prosthetic valve dysfunction, and left atrial masses (Fig. 4-13, Video 4-4).

Nuclear Cardiology

Radionuclide imaging of the heart allows quantification of left ventricular size, systolic function, and myocardial perfusion. For radionuclide ventriculography, the patient's red blood cells are labeled with a small amount of a radioactive tracer (usually technetium-99m).

Left ventricular function can then be assessed by one of two methods. With the first-pass technique, radiation emitted by the tagged red blood cells as they initially flow though the heart is detected by a gamma camera positioned over the patient's chest. With the gated equilibrium method, or multigated acquisition (MUGA) method, the tracer is allowed to achieve an equilibrium distribution throughout the blood pool before count acquisition begins. This second method improves the resolution of the ventriculogram. For both techniques, the gamma camera can be gated to the ECG, allowing determination of the total emitted end-diastole counts (EDCs) and end-systole counts (ESCs). Left

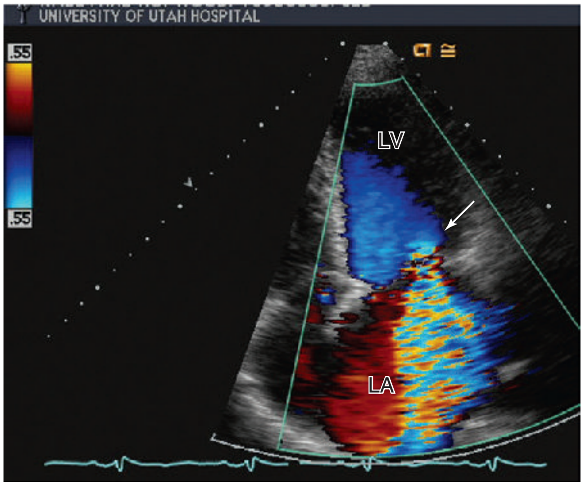

FIGURE 4-11 Color Doppler recording demonstrates severe mitral regurgitation. The regurgitant jet seen in the left atrium is represented in *blue* because blood flow is directed away from the transducer. The *yellow* components are the mosaic pattern traditionally assigned to turbulent or high-velocity flow. The *arrow* points to the hemisphere of blood accelerating proximal to the regurgitant orifice (i.e., proximal isovelocity surface area [PISA]). The size of the PISA can be used to help grade the severity of regurgitation. Video 4-2 shows a dynamic echocardiographic image in a patient with mitral regurgitation. LA, Left atrium; LV, left ventricle. (Image courtesy Sheldon E. Litwin, MD, Division of Cardiology, University of Utah, Salt Lake City, Utah.)