left ventricular mass, they are not generally used for this purpose. Although measurement of wall thickness with echocardiography is relatively straightforward and accurate, determining left ventricular mass by echocardiography requires using one of several formulas that takes into account both wall thickness and ventricular cavity dimensions. Assessment of left ventricular mass by CMR has the advantage of not requiring geometric assumptions and is thus more accurate than echocardiography.

### ASSESSMENT OF LEFT VENTRICULAR SYSTOLIC FUNCTION

Assessment of ejection fraction, or the percentage of blood ejected with each beat, has been the primary method to assess systolic function and is generally calculated by subtracting end-systolic volume from end-diastolic volume and dividing by end-diastolic volume. All cardiac imaging modalities can provide direct measurements of left ventricular ejection fraction (LVEF). As discussed above, tomographic techniques (e.g., CMR, CT, and radionuclide imaging [SPECT and PET]) are generally more accurate and reproducible than echocardiography because there are no geometric assumptions. A LVEF of 55% or greater is generally considered normal, and an LVEF of 50–55% is considered in the low-normal range.

Newer methods to assess systolic function, such as myocardial strain or deformation imaging using speckle-tracking methods on echocardiography or myocardial tagging on CMR, can provide a more sensitive approach to detection of systolic dysfunction. Additional assessments based on these novel methods include assessment of myocardial twist and torsion. Although these techniques are not used routinely, they may be especially useful in certain conditions such as valvular heart disease and early detection of cardiotoxicity following chemotherapy and/or radiation therapy. In addition to estimation or calculation of ejection fraction, stroke volume can be assessed by virtually all cardiac imaging methods, generally by subtracting the end-systolic volume from the end-diastolic volume, or by Doppler methods (only on echocardiography), and offers another measure of systolic function that provides independent information from ejection fraction.

### ASSESSMENT OF LEFT VENTRICULAR DIASTOLIC FUNCTION

Echocardiography remains the primary method for clinical assessment of diastolic function. Recent advances in Doppler tissue imaging allow for accurate assessment of the velocity of myocardial wall motion by assessing the excursion of the mitral annulus in diastole. Mitral annular relaxation velocity, or E′, is inversely related to the time constant of relaxation, tau, and has been shown to have prognostic significance. Dividing the standard mitral inflow maximal velocity, E, by the mitral annular relaxation velocity yields E/E′, which has been shown to correlate with left ventricular filling pressures. The utility of standard E and A wave ratios for assessment of diastolic function has been questioned. Mitral deceleration time can be a useful measure if very short (<150 ms), suggesting restrictive physiology and severe diastolic dysfunction. Several grading methods for diastolic function have been proposed that take into account a number of diastolic parameters, including Doppler tissue-based relaxation velocities, pulmonary venous Doppler, and left atrial size **(Fig. 270e-8)**. Diastolic function worsens with aging, and most diastolic parameters need to be adjusted for age.

### ASSESSMENT OF RIGHT VENTRICULAR FUNCTION

Right ventricular size and function have been shown to be prognostically important in a variety of conditions. Right ventricular size and function can be assessed by echocardiography, CMR, CT, or radionuclide imaging methods. CMR is considered the most accurate noninvasive technique to evaluate the structure and right ventricular ejection fraction of the right ventricle **(Video 270e-2)**. Although first-pass imaging by radionuclide angiography can provide accurate and reproducible measurements of right ventricular volumes and ejection fraction, it is not commonly used. Assessment of the right ventricle by echocardiography has generally been qualitative, owing in part to the unusual geometry of the right ventricle. However, several quantitative methods are available for assessment of right ventricular function, including fractional area change (FAC = [diastolic area – systolic area]/diastolic area), which has been shown to correlate with outcomes in heart failure and after myocardial infarction. Excursion of the tricuspid annulus (tricuspid annular plane systolic excursion) is another widely used method to assess right ventricular function, although it is mostly used in research settings.

Abnormalities of right ventricular size and function are generally secondary to either diseases that affect the right ventricle intrinsically or disease in which the right ventricle responds to abnormalities elsewhere in the heart or pulmonary vasculature. Intrinsic diseases that affect the RV include congenital abnormalities, including hypoplastic right ventricle and arrhythmogenic right ventricular dysplasia, and acquired diseases, such as right ventricular infarction and infiltrative diseases that affect the right ventricle. Long-standing pulmonary hypertension or pulmonary outflow tract obstruction leads to right ventricular hypertrophy and ultimately dilatation. Although right ventricular dilatation can occur due to both chronic and acute processes, chronic right ventricular dilatation is usually secondary to long-standing increases in pulmonary pressures and can thus be distinguished from the acute processes that cause right ventricular dilatation. One such acute process that can cause profound right ventricular dilatation and dysfunction is acute pulmonary embolism. In the setting of acute occlusion of a pulmonary artery or branch, an acute rise in pulmonary vascular resistance causes a previously normal right ventricle to dilate and fail due to the increased afterload. In acute pulmonary embolism, right ventricular dilatation and dysfunction are signs of substantial hemodynamic compromise and are associated with a marked increase risk in likelihood of death. In addition to right ventricular dilatation, acute pulmonary embolism is often associated with a specific pattern of regional right ventricular dysfunction, commonly referred to as the McConnell sign, characterized by preservation of right ventricular wall motion in the basal and apical regions and dyskinesis in the region of the mid right ventricular free wall. This abnormality is highly specific for acute pulmonary embolism and is likely secondary to acute increases in right ventricular load.

Any disease that causes increased pulmonary vascular resistance can lead to right ventricular dilatation and dysfunction. Long-standing chronic obstructive pulmonary disease results in cor pulmonale in which right ventricular pressures become elevated as the right ventricle hypertrophies in response to the increased pulmonary vascular resistance. Acute pneumonia can cause findings that are similar to acute pulmonary embolism. In patients with right ventricular dilatation without obvious pulmonary disease, intracardiac shunts should be considered. The increased flow through the pulmonary vasculature as a result of an atrial septal or ventricular septal defect can, over time, result in elevation in pulmonary resistance with subsequent dilatation and hypertrophy of the right ventricle. Right ventricular dilatation and dysfunction also have prognostic significance in left-sided heart disease and have been shown to be important predictors of outcome in patients with heart failure or acute myocardial infarction.

In addition to assessment of left ventricular structure, assessment of the other cardiac chambers also provides important clues to intracardiac and systemic diseases. Enlargement of the left atrium is common in patients with hypertension and is also suggestive of increased left ventricular filling pressures; indeed, left atrial size is often termed the "hemoglobin $A_{1c}$" of diastolic function, because left atrial enlargement reflects long-standing increase in left-sided filling pressures. Right atrial dilatation and dilatation of the inferior vena cava are common in conditions in which central venous pressure is elevated.

## PATIENT SAFETY CONSIDERATIONS

### RADIATION EXPOSURE

Both cardiac CT and radionuclide imaging expose patients to ionizing radiation. Several recent publications have raised concern regarding the potential harmful effects of ionizing radiation associated with cardiac imaging. The *effective dose* is a measure used to estimate the biologic effects of radiation and is expressed in millisieverts (mSv). However, measuring the radiation effective dose associated with diagnostic imaging is complex and imprecise and often results in varying estimates,