TABLE 265e-2 DETERMINANTS OF STROKE VOLUME

- **I. Ventricular Preload**
  - A. Blood volume
  - B. Distribution of blood volume
    - 1. Body position
    - 2. Intrathoracic pressure
    - 3. Intrapericardial pressure
    - 4. Venous tone
    - 5. Pumping action of skeletal muscles
  - C. Atrial contraction
- **II. Ventricular Afterload**
  - A. Systemic vascular resistance
  - B. Elasticity of arterial tree
  - C. Arterial blood volume
  - D. Ventricular wall tension
    - 1. Ventricular radius
    - 2. Ventricular wall thickness
- **III. Myocardial Contractility**[a]
  - A. Intramyocardial $[Ca^{2+}]$ ↑↓
  - B. Cardiac adrenergic nerve activity ↑↓[b]
  - C. Circulating catecholamines ↑↓[b]
  - D. Cardiac rate ↑↓[b]
  - E. Exogenous inotropic agents ↑
  - F. Myocardial ischemia ↓
  - G. Myocardial cell death (necrosis, apoptosis, autophagy) ↓
  - H. Alterations of sarcomeric and cytoskeletal proteins ↓
    - 1. Genetic
    - 2. Hemodynamic overload
  - I. Myocardial fibrosis ↓
  - J. Chronic overexpression of neurohormones ↓
  - K. Ventricular remodeling ↓
  - L. Chronic and/or excessive myocardial hypertrophy ↓

[a]Arrows indicate directional effects of determinants of contractility. [b]Contractility rises initially but later becomes depressed.

ASSESSMENT OF CARDIAC FUNCTION

Several techniques can define impaired cardiac function in clinical practice. The cardiac output and stroke volume may be depressed in the presence of heart failure, but not uncommonly, these variables are within normal limits in this condition. A somewhat more sensitive index of cardiac function is the ejection fraction, i.e., the ratio of stroke volume to end-diastolic volume (normal value = 67 ± 8%), which is frequently depressed in systolic heart failure even when the stroke volume itself is normal. Alternatively, abnormally elevated ventricular end-diastolic volume (normal value = 75 ± 20 mL/m^2) or end-systolic volume (normal value = 25 ± 7 mL/m^2) signifies impairment of left ventricular systolic function.

Noninvasive techniques, particularly echocardiography as well as radionuclide scintigraphy and cardiac magnetic resonance imaging (MRI) (Chap. 270e), have great value in the clinical assessment of myocardial function. They provide measurements of end-diastolic and end-systolic volumes, ejection fraction, and systolic shortening rate, and they allow assessment of ventricular filling (see below) as well as regional contraction and relaxation. The latter measurements are particularly important in ischemic heart disease, as myocardial infarction causes regional myocardial damage.

A limitation of measurements of cardiac output, ejection fraction, and ventricular volumes in assessing cardiac function is that ventricular loading conditions strongly influence these variables. Thus, a depressed ejection fraction and lowered cardiac output may occur in patients with normal ventricular function but reduced preload, as occurs in hypovolemia, or with increased afterload, as occurs in acutely elevated arterial pressure.

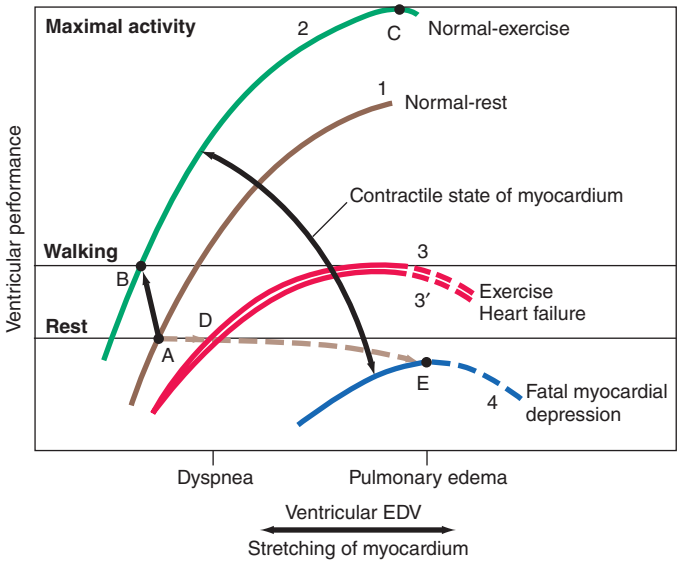

FIGURE 265e-8 The interrelations among influences on ventricular end-diastolic volume (EDV) through stretching of the myocardium and the contractile state of the myocardium. Levels of ventricular EDV associated with filling pressures that result in dyspnea and pulmonary edema are shown on the abscissa. Levels of ventricular performance required when the subject is at rest, while walking, and during maximal activity are designated on the ordinate. The *broken lines* are the descending limbs of the ventricular-performance curves, which are rarely seen during life but show the level of ventricular performance if end-diastolic volume could be elevated to very high levels. For further explanation, see text. *(Modified from WS Colucci and E Braunwald: Pathophysiology of heart failure, in Braunwald's Heart Disease, 7th ed, DP Zipes et al [eds]. Philadelphia: Elsevier, 2005, pp 509–538.)*

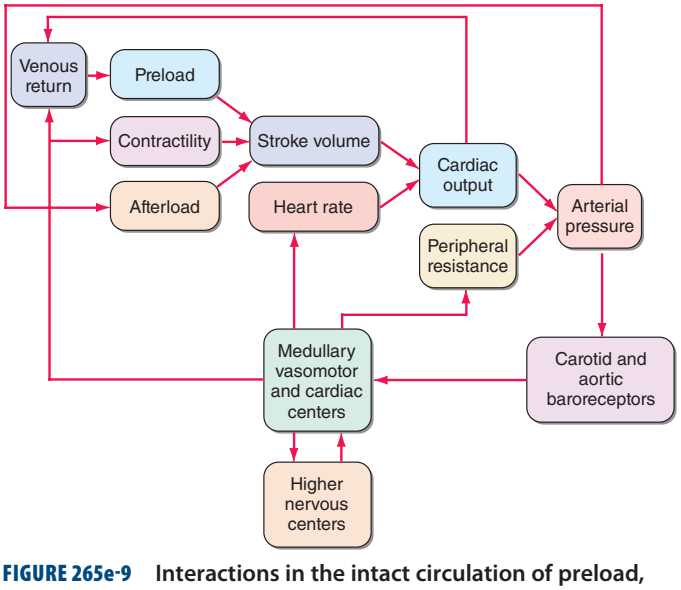

FIGURE 265e-9 Interactions in the intact circulation of preload, contractility, and afterload in producing stroke volume. Stroke volume combined with heart rate determines cardiac output, which, when combined with peripheral vascular resistance, determines arterial pressure for tissue perfusion. The characteristics of the arterial system also contribute to afterload, an increase that reduces stroke volume. The interaction of these components with carotid and aortic arch baroreceptors provides a feedback mechanism to higher medullary and vasomotor cardiac centers and to higher levels in the central nervous system to effect a modulating influence on heart rate, peripheral vascular resistance, venous return, and contractility. *(From MR Starling: Physiology of myocardial contraction, in Atlas of Heart Failure: Cardiac Function and Dysfunction, 3rd ed, WS Colucci and E Braunwald [eds]. Philadelphia: Current Medicine, 2002, pp 19–35.)*