Invasive Hemodynamic Characterization of Heart Failure with Preserved Ejection Fraction

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KEYWORDS

• Invasive hemodynamic assessment • Heart failure with preserved ejection fraction • Dyspnea

KEY POINTS

- Invasive hemodynamic assessment in heart failure with preserved ejection fraction (HFpEF) was originally a primary research tool to advance the understanding of the pathophysiology of HFpEF.
- The role of invasive hemodynamic assessment in HFpEF is expanding to the diagnostic arena where invasive assessment offers a robust, sensitive, and specific way to diagnose or exclude HFpEF in patients with unexplained dyspnea and normal ejection fraction.
- In future years, invasive hemodynamic profiling may more rigorously phenotype patients to individualized therapy and, potentially, deliver novel device-based structural interventions.

INTRODUCTION

The circulatory system serves to deliver substrates to the body via the bloodstream while removing the byproducts of cellular metabolism. Hemodynamics broadly refers to the study of the forces involved in the circulation of blood, which are governed by to the physical properties of the heart and vasculature and their dynamic regulation by the autonomic nervous system. Before discussion of cardiac properties, the extrinsic forces modulating cardiac function must be defined.

Load and Cardiac Function

Afterload represents the forces opposing ventricular ejection and can be quantified by systolic left ventricular (LV) wall stress and aortic input impedance or its individual components (resistance, compliance, characteristic impedance).[1] Wall stress is inconvenient because it depends on heart size and geometry, whereas impedance is cumbersome because it is a frequency-domain parameter that cannot be easily coupled with time-domain measures of ventricular function. Effective arterial elastance (Ea), defined by the ratio of LV end-systolic pressure (ESP) to stroke volume, provides a robust measure of total arterial load. Ea is not a directly measured parameter but, instead, a net or lumped stiffness of the vasculature that incorporates both mean and oscillatory components of afterload (**Fig. 1**).[1]

Preload reflects the degree of myofiber stretch before the onset of contraction, which, in turn, dictates the force and velocity of contraction according to the Frank-Starling principle.[1] In everyday practice, preload is often conceptualized as equivalent to LV filling pressures. However, in fact, preload is most accurately reflected by the LV volume at end-diastole volume (EDV). Filling pressures are related to EDV by the LV diastolic chamber stiffness, which differs in healthy volunteers and subjects with HFpEF.

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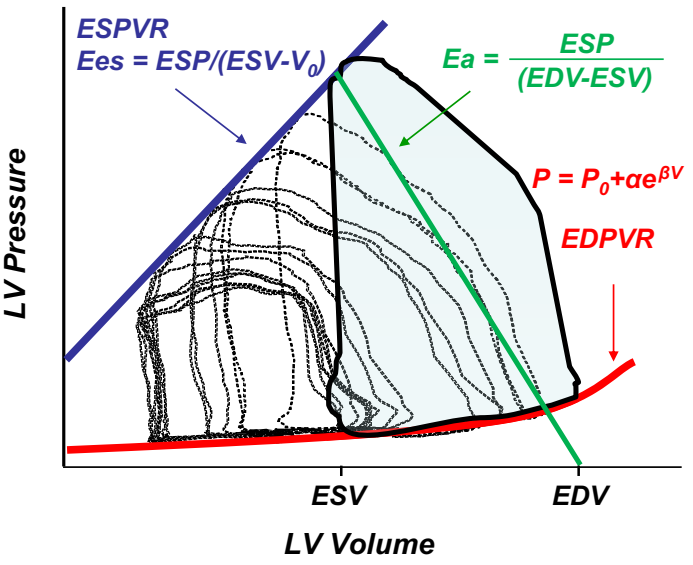

Fig. 1. Ventricular-arterial coupling in the pressure-volume plane. Pressure-volume loop at steady state is shown in dark black. The area subtended by the loop (*shaded*) represents the stroke work. Stroke volume is the difference between end-diastolic volume (EDV) and end-systolic volume (ESV). Ea is defined by the negative slope connecting the ESP and ESV coordinates with EDV and pressure = 0. With acute preload reduction (*dotted line loops*) there is progressive reduction in EDV, ESV, and ESP. The linear slope of the end-systolic pressure volume relationship (ESPVR) is LV end-systolic elastance (Ees). The curvilinear slope of the end-diastolic pressure–volume relationship (EDVPR) is derived by fitting pressure-volume coordinates measured during diastasis to the equation shown. The exponential power or stiffness constant (β) obtained is a measure of LV diastolic stiffness. (*Adapted from* Borlaug BA, Kass DA. Invasive hemodynamic assessment in heart failure. Heart Fail Clin 2009;5(2):217–28; with permission.)

Systolic Function

Ejection fraction (EF) is the most common clinical measure of LV systolic function, but EF is a poor measure of contractility because of its dependence on load and chamber size. For example, an acute decrease in afterload enhances EF in the absence of any change in contractility.[1] Isovolumic and ejection phase indices such as the maximal rate of pressure increase (dP/dt_{max}) and stroke work (SW) are independent of afterload but vary directly with preload (EDV).[2,3] More robust measures of contractility that are independent of preload and afterload include the slope of the relationship between SW and EDV (preload recruitable SW [PRSW]), stress-corrected fractional shortening (sc-FS), LV peak power index, and LV end-systolic elastance (Ees).[1,2,4,5] The latter, which describes the total stiffness attained by the LV at end-systole, is expressed graphically by the slope and intercept of the ESP–volume relationship (ESPVR). Ees is commonly examined in the context of Ea to assess ventricular-arterial coupling (see Fig. 1). In addition to inotropic state, Ees is sensitive to chamber remodeling and passive viscoelastic properties, meaning that it can be elevated even when systolic function is depressed.[5]

Diastolic Function

During early diastole there is rapid decay in LV pressure caused by active relaxation (thick-thin filament dissociation, ATP-dependent calcium reuptake) and generation of negative intraventricular pressure gradients due to elastic recoil of constituents that were compressed in the preceding contraction.[6] This negative pressure gradient or suction effect enhances the atrioventricular pressure gradient leading to mitral valve opening.[7] This suction function is very important in the normal heart, which can fill even at zero pressure. Approximately 80% of filling is achieved during early diastole, with little increase in LV pressure. Invasively obtained parameters quantifying early-phase LV diastolic function include the time constant of pressure decay during isovolumic relaxation (τ), the maximal rate of pressure decay (dP/dt_{min}), and the minimal diastolic LV pressure achieved (LV_{min}).[8]

As chamber filling progresses, the atrioventricular pressure gradient dissipates and flow decelerates, leading to the period of diastasis in which mitral inflow is absent. Because flow is nil during this phase and relaxation is usually complete, diastasis represents the ideal period in which to assess passive LV stiffness. In research studies, passive chamber stiffness is assessed according to the slope and intercept of the diastolic pressure–volume relationship (DPVR; see Fig. 1).[8] Unlike the ESPVR, the DPVR is curvilinear, becoming more vertical (greater increase in pressure) at higher volumes. The DPVR can be assessed using single-beat and multibeat techniques. The single-beat technique simply plots LV pressure versus volume for a single