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Ventricular—arterial coupling: Invasive and non-invasive assessment

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Abstract Interactions between the left ventricle (LV) and the arterial system, (ventricular—arterial coupling) are key determinants of cardiovascular function. Ventricular—arterial coupling is most frequently assessed in the pressure—volume plane using the ratio of effective arterial elastance (E_A) to LV end-systolic elastance (E_{ES}). E_A (usually interpreted as a lumped index of arterial load) can be computed as end-systolic pressure/stroke volume, whereas E_{ES} (a load-independent measure of LV chamber systolic stiffness and contractility) is ideally assessed invasively using data from a family of pressure—volume loops obtained during an acute preload alteration. Single-beat methods have also been proposed, allowing for non-invasive estimations of E_{ES} using simple echocardiographic measurements. The E_A/E_{ES} ratio is useful because it provides information regarding the operating mechanical efficiency and performance of the ventricular—arterial system. However, it should be recognized that analyses in the pressure—volume plane have several limitations and that "ventricular—arterial coupling" encompasses multiple physiologic aspects, many of which are not captured in the pressure—volume plane. Therefore, additional assessments provide important incremental physiologic information about the cardiovascular system and should be more widely used. In particular, it should be recognized that: (1) comprehensive analyses of arterial load are important because E_A poorly characterizes pulsatile LV load and does not depend exclusively on arterial properties; (2) The systolic loading sequence, an important aspect of ventricular—arterial coupling, is neglected by pressure—volume analyses, and can profoundly impact LV function, remodeling and progression to heart failure. This brief review summarizes methods for the assessment of ventricular—arterial interactions, as discussed at the Artery 12 meeting (October 2012).

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The interactions between the left ventricle (LV) and systemic arteries are key determinants of cardiovascular function. This brief review deals with various approaches used for the assessment of ventricular—arterial interactions and coupling, with a focus on underlying physiologic principles and the interpretation of various indices obtained with invasive and non-invasive methods, as discussed in the 12th meeting of the Association for Research into Arterial Structure and Physiology (ARTERY 12, Vienna, October 2012).

Analyses in the pressure—volume plane

The LV pressure—volume loop is a plot of LV instantaneous cavity pressure and volume throughout the cardiac cycle. When volume and pressure are plotted in the horizontal and vertical axes, respectively, instantaneous pressure—volume pairs proceed in a counter-clock wise manner, defining a loop (Fig. 1A). The lower right "corner" of this loop represents end-diastole. Isovolumic LV contraction results in an increase in LV pressure without an increase in LV volume (vertical line). After aortic valve opening, LV volume decreases as the LV ejects blood, which results in a leftward shift of the instantaneous pressure—volume points. At the end of ejection, aortic valve closure is followed by a drop in LV pressure before mitral valve opening (isovolumic relaxation), resulting in a vertical line in the PV loop. After mitral valve opening, diastolic suction continues until the end of relaxation, which is followed by passive filling of the cavity with increasing pressure until end-diastole. Late diastolic passive filling follows a non-linear pattern in the pressure—volume plane.

The LV as an elastance

The concept of the time-varying LV elastance and its role in LV pump function and myocardial energetics was first formulated by Suga and Sagawa several decades ago.[1—4] When a "family" of pressure—volume loops are obtained from the same subject during acute preload or afterload alterations at constant inotropic state, the left upper loop corners (end-systolic pressure—volume points) describe the end-systolic pressure—volume relation (ESPVR). The LV end-systolic elastance (E_{ES}) is quantified as the slope of the ESPVR, which is generally assumed to be linear. Fig. 1B shows a schematic representation of PV loops from a hypothetical subject, obtained during 3 beats under different pre-load conditions. The 3 points corresponding to end-systole can be connected with a line, the slope of which is E_{ES}. V_0 is the volume-axis intercept of the ESPVR, which represents a purely theoretical volume at zero pressure, assuming a linear ESPVR. E_{ES} is an index of the contractility and systolic stiffness of the LV. As such, it is affected by the inotropic state of the myocardium and in the long-term, by geometric remodeling and biophysical myocardial tissue properties (which in turn depend on stiffness of myocardial cells, fibrosis and other factors).[5,6]

The end-systolic elastance concept is intuitive because it is based on a well-defined time point in the cardiac cycle. However, a pressure—volume relationship exists at each instant during the cardiac cycle, giving rise to the concept of the "time-varying" elastance (Fig. 1C—D). Fig. 1C shows a representative family of LV instantaneous pressure—volume relationships based on joining instantaneous pressure—volume points that occur at similar times during the cardiac cycle in different beats ("isochrones"). The slope of these isochrones increases during systole and becomes

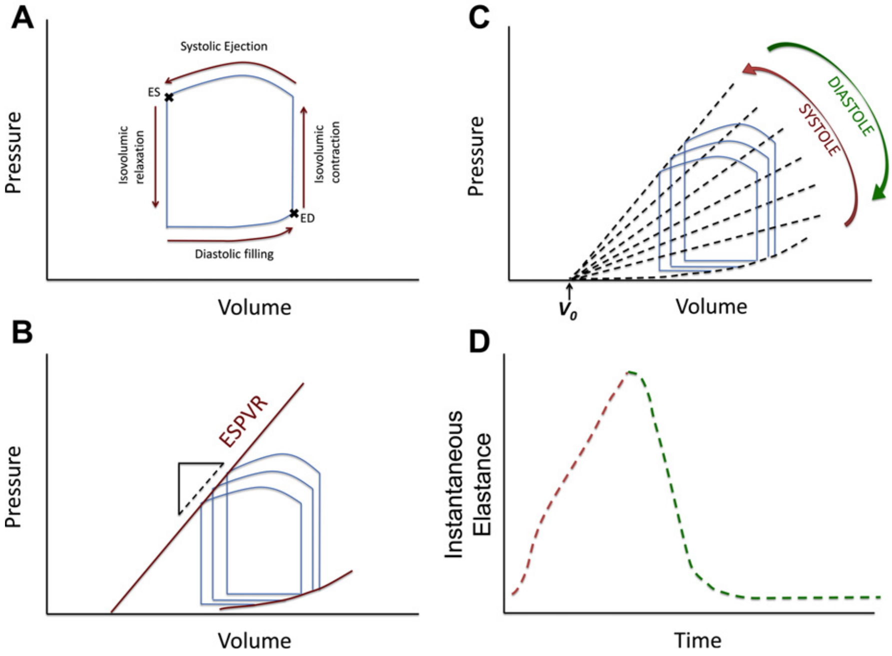

Figure 1 A: LV pressure—volume relation in a single beat; B: End-systolic and end-diastolic pressure—volume relations obtained from a "family" or pressure—volume loops; C: Instantaneous isochrones during the cardiac cycle (note the assumption of a common volume-axis intercept, V_0); D: Time-varying elastance curve, obtained from plotting the slope of the isochrones over time.