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Editorial Commentary

Assessing Left Ventricular Performance
A *Rashomon* Effect

Giovanni de Simone, Richard B. Devereux

The physiology of conduit arteries can be approximated noninvasively. One simple method to estimate arterial load is by computation of effective arterial elastance (E_a). E_a incorporates the steady component (peripheral resistance) and the pulsatile components of arterial load, including total arterial compliance and aortic characteristic impedance. Invasive studies and simulations have shown that E_a can be approximated by the ratio of left ventricular (LV) end-systolic pressure to stroke volume in normal and hypertensive human subjects.[1,2] An important practical advantage of the calculation of E_a is the merging of all components of arterial load into a single quantitative variable, although it has the limitations of not separating the relative contributions of steady and pulsatile components[2] and of relative sensitivity to variation of heart rate.[3]

E_a influences stroke volume and is related to LV contractility, as assessed at end ejection by the pressure-volume loop and determination of the LV elastance (E_{max}).[4,5] Thus, E_a has been combined with E_{max}, the slope of a regression line connecting end-systolic pressures and volumes obtained at different loading conditions. The ratio E_a/E_{max} is widely used as a measure of LV-arterial coupling. As emphasized recently by Baicu et al,[6] LV function, LV performance, LV contractility, and myocardial contractility are not interchangeable terms. Experimental studies suggest that LV performance, measured as stroke work (SW),[6] is maximal when $E_{max}=E_a$. LV performance increases its efficiency when, for a given SW, myocardial oxygen consumption is lower. The optimal efficiency of LV performance is achieved at $E_a=0.5E_{max}$.[5,7] However, beyond these clear-cut limits, there is also evidence that SW may remain near maximal for a broad range of E_a/E_{max} values,[7] mostly depending on the magnitude of preload and preload-recruitable SW.[8]

In addition to end-ejection phase indices, LV contractility can also be measured by isovolumic phase indices (peak positive dP/dt) and ejection phase indices (end-systolic wall stress versus fractional shortening). Because measures of LV contractility using LV volumes or shortening assess the inotropic state of the LV chamber, they may be influenced by LV geometric changes that alter the relation of the chamber to myocardial contractility.[9]

LV Function, Performance, and E_a/E_{max} in Hypertension

In this issue of the journal, Osranek et al[10] demonstrate noninvasively that optimal control of arterial hypertension can shift LV work from maximal SW ($E_a/E_{max}\approx1$) to optimal efficiency ($E_a/E_{max}\approx0.5$). In other words, after optimal control of blood pressure, the lower E_a/E_{max} suggests that the left ventricle may develop the same amount of work with much lower oxygen consumption. The authors attribute this dramatic improvement to a possible increase in the coronary blood supply, as suggested by the Buckberg index (ie, the ratio between the diastolic and the systolic areas under the pressure waveform). However, as they recognize, the improvement of LV-arterial coupling is substantially related to a near doubling of the E_{max} value but little change in E_a. Thus, the whole result of the study seems to be driven by a remarkable improvement in end-ejection phase LV contractility. Although the change in E_{max} is very evident, the results concerning LV function and performance are less clear, although equally interesting.

Although LV efficiency and contractility improved substantially and myocardial afterload (end-systolic stress) markedly decreased in the group of hypertensive patients studied by Osranek et al,[10] ejection fraction did not change or even tended to decrease. It is likely that LV midwall shortening, a more direct measure of wall mechanics and myocardial contractility, especially in the presence of concentric LV geometry,[11] did not change, as suggested by the unchanged relative wall thickness. Because end-systolic stress was significantly reduced at rest, the apparently inconsistent lack of an increase in ejection fraction or implicit midwall shortening despite substantially increased chamber contractility (as measured by E_{max}) would be that either preload or myocardial contractility is reduced after treatment, blunting the expected increase in ejection-phase indices. Actually, in hypertension trials, it is common that resting LV chamber systolic function does not change after reduction of blood pressure and myocardial afterload, but this is usually attributable to modifications of LV geometry and consequent mechanical changes.[9] When this occurs, reduction of blood pressure is usually paralleled by regression of LV hypertrophy and improvement of midwall shortening.[12] However, this mechanism cannot be invoked to explain the findings of Osranek et al,[10] because in their patients neither LV mass (which can be estimated from reported LV end-diastolic volume and relative wall thickness) nor relative wall thickness were reduced after normalization

of blood pressure, and midwall shortening is likely to follow the trend of ejection fraction.

Resting Conditions or Load Challenges

Taken together, Osranek et al[6] demonstrate a dramatic effect of normalization of blood pressure on end-ejection indices of LV contractility, driving improvement in LV efficiency and LV-arterial coupling, in the absence of changes in LV geometry, without visible benefit in the ejection-phase indices, an apparent inconsistency that needs to be reconciled. The main resting LV function parameters showed no improvement between baseline and end treatment. Instead, eg, the simple end-systolic pressure/volume ratio, often used as single-point index of LV elastance, tended to decrease after treatment from ≈ 1.8 to 1.3, paralleling the nonsignificant decrease of LV ejection fraction. In contrast, this ratio remains near identical after the load increase by handgrip (≈ 1.7 versus 1.6) consistent with the benefit found by calculating the E_{max} slope. Resting stroke volume tended to be reduced, albeit not significantly, paralleling ejection fraction. Average stroke volume fell by ≈ 7 mL with handgrip at baseline, whereas it increased by a mean of 5 mL after normalization of blood pressure. The difference in the stroke volume response to handgrip might be statistically significant. Thus, whereas the small increase in cardiac output with baseline handgrip was only attributable to the increase in heart rate, counterbalanced by the decreased stroke volume, after treatment, the significant increase of cardiac output with handgrip was attributable to a smaller increase in heart rate and some stroke volume contribution, a much more energetically convenient adaptation.

Thus, the full benefit of improved arterial-ventricular coupling found in these patients could only be identified with the load challenge by handgrip, whereas the LV function benefits at rest were at best equivocal. This does not mean that changes in response to LV load challenge are more clinically important than treatment-related changes identified at rest, for which extensive evidence of benefit exists, but only that there are differences between resting evaluation and assessment of load challenge response.

LV performance and energy expenditure are influenced by multiple combinations of preload, LV contractility, heart rate, arterial resistance, and compliance, all elements with great variability under many physiological conditions. However, to optimize LV energetics, a unique combination of LV contractility, heart rate, and arterial impedance characteristics needs to be arranged.[5] Most changes reported in the study of Osranek et al[10] are related to the integrated LV response to isometric exercise stimulation. Isometric exercise causes central cardiac and hemodynamic responses different from those of endurance exercise.[13] Compared with the volume overload imposed by moderate endurance exercise, isometric exercise increases total peripheral resistance (1 component of E_a), causing a disproportionate increase in blood pressure and heart rate and imposing or increasing the LV pressure overload.[14] As a consequence, end-systolic pressure increases. With isometric exercise, SW increases because of higher end-systolic pressure, whereas stroke volume does not change (Figure) with a modest increase in cardiac output
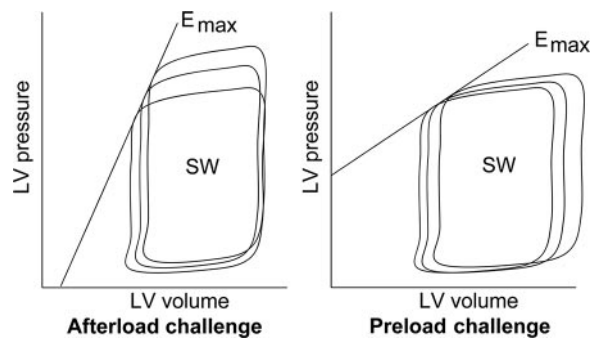
Figure. LV pressure-volume loop at different loading conditions with respective E_{max}. The left panel shows a pressure challenge; the right panel shows a volume challenge. In the left panel, SW increases because of increased developed pressure; in the right panel, SW increases because of increased stroke volume with marginal changes in the developed pressure because of recruitment of Starling forces. At the same level of myocardial contractility, the resulting E_{max} might be very different.

because of higher heart rate. In contrast, endurance exercise imposes a volume overload and SW increases because of higher stroke volume as a consequence of recruitment of Starling forces. Heart rate increases with less change in end-systolic pressure (Figure). E_{max} differs in the 2 conditions,[15] as does E_a.

Conclusions

The sole use of the end-ejection pressure-volume relation to assess LV contractility implies "renunciation of important information."[15] Assessment of stress-length relations is indispensable for the assessment of myocardial function under conditions of changed ventricular geometry.[15] The findings of Osranek et al[10] are interesting, because improved end-systolic measures of LV function are not paralleled by a change in ejection fraction despite reduced LV wall stress. When this occurs, information beyond what is provided by end-ejection indices is needed to understand potentially explanatory roles of changes in indices of preload or other measures of LV myocardial contractility.

Rashomon was a masterpiece of the Japanese movie-director Akira Kurosawa, representing the same reality, an act of violence, under very different perspectives of 4 eyewitnesses. At the end of the movie, the spectator is astonished because there is not absolute truth in the story but only personal visions of what happened.[16]

Disclosures

None.

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