In 1991, Kass and Beyer (3) revisited the pressure–volume relation and found that when stroke work was divided by the square of the end-diastolic volume (EDV²), stroke work remained independent of preload and afterload changes. They called this index “preload-adjusted maximal power” and suggested applying this index as a clinical marker of myocardial performance now that technologic advances in echocardiography allowed accurate estimates of volume changes through the cardiac cycle. Kass and Beyer (3) explained the preload independence of the index as follows: Mean power is the product of mean pressure and flow; pressure is the product of flow and resistance; and, therefore, power is the product of resistance and flow squared. Power divided by volume squared is then proportional to resistance divided by seconds squared. Mean arterial resistance is minimally altered with steady state changes of circulating volume. Thus, at constant heart rate and contractility, preload-adjusted maximal power reflects contractility (3).

In response to this suggestion, Mandarino et al. (4), in this issue of the Journal, report the results of their derivation of preload-adjusted maximal power using automatic border detection (ABD) from canine echocardiographic images to measure cross-sectional area changes (dA/dt) through the cardiac cycle. The product of dA/dt and instantaneous central arterial pressure yields a stroke work analog that is adjusted for loading conditions by the term EDV³/² based on the substitution of dA/dt for dV/dt (Kass and Beyer [3] used EDV² instead of EDV³/² as a correction term because they used dV/dt). The resulting preload-adjusted maximal power index was found to be independent of preload changes experimentally achieved through vena caval occlusions and independent of afterload changes through aortic occlusion.

**Potential limitations of preload-adjusted maximal power as a clinical index of myocardial performance.** First, as noted by Mandarino et al. (4), the contribution of the autonomic nervous system is ignored in this canine model. This effect may be important in humans subject to continuous inotropic and chronotropic modulation by the autonomic nervous system.

Second, the studies of Kass and Beyer (3) and Mandarino et al. (4) were performed in normal dog hearts. Underestimation of true myocardial stroke work may occur in patients with severely dilated cardiomyopathies, where the denominator term is EDV² or EDV³/².

Third, a noninvasive surrogate of central arterial pressure is highly preferable to an invasive measurement for clinical application. Although studies (5) have been performed to correlate pressures in the carotid or femoral arteries using ultrasound transducers, the procedure is too burdensome to make it practical.

Fourth, most pharmacologic interventions, including dobutamine, will affect not only contractility but other variables as well, such as afterload. These interrelated hemodynamic effects must be carefully considered before drawing the conclusion that preload-adjusted maximal power is a load-independent measure of end-systolic elastance.

**Future steps in the development of preload-adjusted maximal power as an index of myocardial performance.** A successful index must be easy to use and to understand. The variables necessary to calculate preload-adjusted maximal power include central arterial pressure, instantaneous EDV and ESV. The index is unlikely to gain wide acceptance unless a noninvasive surrogate of central arterial pressure is used. Mean peripheral arterial pressure is probably the best correlate of mean central arterial pressure. Although instantaneous central arterial pressure cannot be obtained, mean peripheral arterial pressure in the steady state may be an acceptable substitute if supported by future studies. EDV and ESV may be measured accurately by tedious volume manual planimetry but may provide a more accurate component of preload-adjusted maximal power than ABD-derived area from a single plane, especially in hearts with altered geometry. Because the index is not intuitively physiologic (units are mW/cm²), a range of normal and abnormal values must be established.

The index must be demonstrably superior to ejection fraction. Despite its shortcomings, ejection fraction is the preferred index of myocardial function because of its simplicity, reproducibility and prognostic value. Only if an index such as preload-adjusted maximal power turns out to be robustly independent of preload and afterload factors can it improve on the prognostic power and accuracy of ejection fraction.
The evolutionary refinements in echocardiography may now provide the tools for transferring benchwork pressure–volume studies to the clinical arena.

References

2. Patterson SW, Starling EH. On mechanical factors which determine output of ventricles. J Physiol (Lond) 1914;48:37.

Abbreviations and Acronyms

- ABD = automatic border detection
- \( \frac{dA}{dt} \) = rate of change of left ventricular cross-sectional area
- \( \frac{dV}{dt} \) = rate of change of left ventricular volume
- EDV = end-diastolic volume
- ESV = end-systolic volume