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EDITORIAL COMMENT

The Tei Index as an Expression of Right Ventricular Impairment and Recovery

Investment Grade or Subprime?*

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The mechanics of a normal ventricular contraction are precise. The cardiac cycle can be divided into the cyclical sequence of systolic ejection, isovolumic relaxation, diastolic filling, isovolumic contraction, and the next systole. This sequence is mediated by a chain of high-energy steps that include the rapid intracellular recycling of calcium ions within the contractile proteins; the timing of the components of the cycle is reflective of the health of myocardial cells and their coordinated response to loading conditions and contractile state.

See page 143

In the 1960s, before the availability of echocardiography/Doppler, Weissler et al. (1) proposed and investigated a noninvasive expression of myocardial efficiency by using the carotid pulse tracing, the electrocardiogram (ECG), and the phonocardiogram. From these graphic recordings, they calculated the time from the initiation of electrical activity needed to recruit the contractile elements and begin ejection and called it the pre-ejection period (PEP). A second calculation, the time the left ventricle spent in ejection, was called the left ventricular ejection time (LVET). These intervals (collectively called systolic time intervals) were combined into a ratio, PEP/LVET. The authors of studies comparing this ratio to angiography and other invasive expressions of cardiac function found that, in normal subjects, the index increased as systolic function worsened. In other words, as the heart grew more impaired, it took longer to recruit adequate energy to begin ejection and that, once begun, ejection was briefer. Enthusiasm dimmed for systolic time intervals when they were found to be load dependent and variable (2) and was extinguished when echocardiography provided a direct measure of left ventricular systolic function. Despite the fact that echocardiography of the aortic valve combined with ECG provided a direct measure of PEP/LVET (3), interest in systolic time intervals was not revived. Another attempt to simplify the technique was made by Mancini et al. (4), who included isovolumic contraction (IVCT) and relaxation times (IVRT) in their proposed isovolumic index [(IVCT + IVRT)/LVET] by using the peak of the R-wave on the electrocardiogram to onset of mitral valve opening on the echocardiogram to determine IVCT + IVRT. This technique was weakened by variation from electromechanical delay.

With the advent of Doppler echocardiography, the measurement of cardiac time intervals can be made solely from standard echocardiography/Doppler, eliminating the element of electromechanical delay. In 1995, Tei et al. (5) proposed a modification of systolic time intervals, the myocardial performance index (or the Tei index) = [(IVCT + IVRT)/LVET], as a measurement that takes into account those time intervals where energy is developed, work is performed, and relaxation occurs.

Since its description, the myocardial performance index (MPI) has appeared in at least 2,000 published studies, many of which demonstrate its ability to predict outcomes across a spectrum of heart disease. The authors of a minority of these studies have applied the index to the right ventricle, and a few others have derived it from Doppler tissue imaging (DTI) from either ventricle. Regardless of

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this level of interest, it has never been clear that the addition of isovolumic relaxation time to Weissler's original formulation conferred more than an incremental advantage, and at least one comprehensive study has shown that there is no advantage to MPI over the original formulation of systolic time intervals (6). A more serious consideration concerning the MPI resides in its potential sensitivity to loading conditions. Among the many references utilizing this index, however, we could find only one meticulous study (7) that examines MPI in relationship to loading conditions. That study suggests that the index is highly load dependent and is not reliably reflective of contractility.

Right Ventricular (RV) Tei Index: A Measure of RV Function and Pulmonary Hemodynamics

As the result of its complex geometry and position, characterization of RV function by 2-dimensional echocardiography has remained a challenge since the initial measurements of RV volumes and dimensions in 1979 (8). In this issue of *iJACC*, the senior author of the original description of 2-dimensional RV quantitation, Blanchard et al. (9), has again demonstrated a dedication to improving measurements of right ventricular function and their response to treatment by investigating the suitability of the MPI as a measure of RV function As proof of principle, the authors chose a unique group of patients available in their institution and characterized by reduced RV function due to chronically increased but potentially reversible RV afterload. These 93 patients with chronic thromboembolic pulmonary hypertension (CTEPH) provided the opportunity to study severely compromised RV function before and after relief of chronic afterload stress by thromboendarterectomy. By using the MPI derived from DTI, the authors found that the MPI was increased (i.e., more abnormal) in patients with CTEPH compared with normal patients (0.52 ± 0.19 vs. 0.27 ± 0.09; $p < 0.0001$) and decreased (i.e., improved) to 0.33 ± 0.10 ($p < 0.0001$) after thromboendarterectomy. Pulmonary vascular resistance (PVR) was correlated with RV MPI before and after surgery ($r = 0.78$ and $r = 0.67$, respectively; $p < 0.0001$), and the change in PVR with the change in RV MPI ($r = 0.75$; $p < 0.0001$).

Interestingly, there was a significant decrease noted in isovolumetric times after surgery, but no significant change in RV ejection time, implying reductions in afterload but persistence of RV dysfunction. These observations highlight the importance of load on RV performance. Furthermore, both RV MPI and PVR varied significantly with the degree of RV enlargement. On the basis of these results, the authors conclude that, in patients with CTEPH, RV MPI may be a valuable marker to monitor disease severity before and after thromboendarterectomy.

We applaud the authors in showing utility of the RV MPI in patients with CTEPH as a variable of myocardial performance that may well reflect the underlying pathophysiology and disease severity of these surgically treated patients. However, several limitations to this study should be noted. First, specific patient data, including ECG data and medication use at baseline and after surgery, are not provided. Changes in conduction, such as right bundle branch block, may result in subtle-but-significant prolongation of cardiac time intervals and variation in the MPI (10). Given that MPI is load dependent, acute perioperative or postoperative changes in medication that affect pre-load and afterload may skew the MPI. Second, considerable overlap and scatter among the subgroups blurs the relationship of MPI with post-operative PVR (see Fig. 4 in Blanchard et al. [9]). For example, at an MPI of 0.35, the postoperative PVR ranges from 100 to 650 dynes·s/cm^5. Third, there are technical difficulties in acquiring and measuring low-amplitude signals in DTI may be expected to introduce variation in calculated MPI. As seen in Figure 1 in Blanchard et al. (9), the acquired data from which measurements are made do not have well-defined borders. Fourth, the RV MPI as an isolated measure of myocardial performance may be vitiated when viewed through the lens multivariate analysis. Finally, as pointed out by the authors, the utility of this index is yet to be determined and will require further research when prognostic and outcome data become available.

Future Directions

The right ventricle, with its complex shape and geometry, is difficult to encompass and characterize with echocardiography. Although there have been attempts to quantitatively characterize right ventricular size and function, no single variable has consistently performed well. With the development of novel 3-dimensional echocardiographic techniques, RV size and function in healthy individuals may be estimated with good accuracy, when compared with magnetic resonance imaging (11). Continued experience with this technique may overcome the challenges in characterizing the diseased RV.

Despite the stream of publications that the MPI has spawned, we must rate the application of MPI to changes in right ventricular function after CTEPH embolectomy as more subprime than investment grade while anticipating an ultimate upturn in methodology.

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Key Words: right ventricular function ■ pulmonary hypertension ■ pulmonary embolism ■ chronic thromboembolic pulmonary hypertension ■ pulmonary thromboendarterectomy ■ Doppler echocardiography ■ right ventricular myocardial performance index ■ systolic time intervals.